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AN UNRECOGNIZED PATHWAY FOR BACTERIAL INVASION OF THE RESPIRATORY TRACT

By M. C. Winternitz, G. H. Smith and E. S. Robinson

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When a preliminary injury has destroyed the efficiency of the protective mechanism in the upper respiratory tract, it is easy to [illegible] the portal of entry and to follow the course of microörganisms associated with pneumonia. But we know that inflammation of the lung can occur when no gross lesion of the upper respiratory tract exists. In the latter condition, how do bacteria reach the lung? This is the question we have sought to answer, and the results of our experience, briefly stated, indicate that in such cases the rich plexus of lymphatics within the submucosa of the trachea supplies the requisite pathway.

The theories concerned with pulmonary infection have been greatly influenced by the anatomical relations of the lungs and trachea. Naturally, the external communication of the lungs through the bronchi and trachea suggested that bacteria entered by this route and caused pneumonia. And it is well known that foreign material may reach the lung in this way; carbon particles, for example, are encountered within the pulmonary tissue at autopsy almost as a routine. The importance of this route is illustrated also by cases of aspiration pneumonia. On the other hand, the structure of the tracheal and bronchial lining, with its covering of ciliated, mucus-secreting epithelium, renders it difficult for foreign materials to reach the lung, and it is fair to assume that under normal conditions this protective mechanism is a competent one. Furthermore, evidence of the adequate nature of this protective mechanism is provided by the results of a large number of experiments in which both pyogenic organisms and tubercle bacilli were used. The inhalation of such organisms is without effect unless the respiratory tract has first been irritated or damaged. It is true, of course, that when the functional capacity of the mechanism is lost pneumonia follows. This has been clearly demonstrated in the study of pulmonary irritating gases.[1]

In reaching a conclusion concerning the pathway of infections to the lungs in various types of pneumonia, the difficulty has depended largely upon the fact that the disease could not be reproduced experimentally with a desirable degree of regularity and certainty. In many instances the conditions imposed by the experiment were so artificial that they might not be considered as factors in spontaneous infection. The intrabronchial insufflation method is, of course, the one in mind. The lobar, lobular and interstitial types of pneumonia have all been produced by insufflation, and they have also been produced by needle puncture of the trachea through the skin of the neck.[2]

[1] Experimental Studies on the Lesions Produced by Poisonous Gases, M. C. Winternitz *et al.* Yale University Press, 1919.

[2] A comprehensive review of the literature, together with valuable contributions to this subject, has been presented by Wadsworth. Am. Jour. Med. Sci., 1904, CXXVII, 851.

From our studies of pulmonary irritating gases[3] and influenza,[4] it seemed logical to divide the pneumonias into two groups; namely, those secondary to damage of the protective mechanism of the upper respiratory tract, and those in which such damage was not demonstrable. Concerning the pathway of the infection in the latter type of the disease, no explanation has been suggested other than that noted above; namely, that the pathway of the microörganisms was through the lumen of the trachea and bronchi. As has been said, this seems unsatisfactory in view of the physiology of the larger air passages. The question of a primary invasion of the blood stream requires no historical discussion, since although evidence is at hand that early infection of the circulation occurs, an adequate explanation of how the organisms reach the blood stream has never been advanced.

The production of lobar pneumonia in monkeys by intratracheal inoculation by the needle puncture route has recently been reported by Blake and Cecil.[5] The question arises then: How can pneumonia be produced in this way, if as has been assumed, the epithelium of the upper respiratory tract is a competent protective mechanism? The one point of departure from insufflation in this experiment is the needle puncture of the wall of the trachea and subcutaneous tissues. This needle, though sterile on entry, is unquestionably infected when it is withdrawn, and consequently a possible path of infection to the lung may be found elsewhere than through the lumen of the trachea. The experiments recorded below indicate that this supposition is correct.

The Submucosa of the Trachea and Bronchi as a Pathway of Infection to the Lung

Rabbits were inoculated into the trachea through the skin of the neck by needle puncture. Pneumococci of established virulence were employed. Invariably the animals died of septicemia which began shortly after the inoculation and persisted until death. The period of survival after inoculation varied; in some instances it extended over six days. Infection of the needle path was found regularly, and in some animals the lesion involved not only the tracheal submucosa, but also the peritracheal and subcutaneous tissues. Whenever the subcutaneous tissue was involved, a severe cellulitis extended from the submaxillary to the thoracic region. Where the infection was less superficial, cellulitis and phlegmon were occasionally demonstrable in the deeper fascial planes of the neck. Sometimes the infection was confined chiefly to the submucous and peritracheal tissues, and in a few cases it was limited, except microscopically, to the submucosa itself. The inflammatory process in the submucosa could be traced grossly. From the point of inoculation it extended below the bifurcation of the trachea and into the larger extrapulmonary bronchi. In all instances there was involvement of the thoracic viscera and serous surfaces. Pericarditis, pleuritis and mediastinitis were frequent, but their occurrence bore no absolute relationship to the extent of the inflammatory involvement of the lung itself. Frequently, several lobes of the lung were involved by a diffuse inflammatory process. Grossly, the lungs appeared more voluminous than normal, and despite their increased volume, contained much less air than usual. Occasionally, especially in animals which survived the inoculation for a relatively longer time (3 to 6 days), one of the lobes of the lung was found to be more voluminous than the others and definitely hepatized. As a rule, the consolidation was lobular. The microscopic examination corroborated the gross picture just described. In some of the sections the needle tract itself was included, and there minute damage to the epithelium of the trachea was demonstrable, together with the presence of a small amount of exudate at the point of entry. The remainder of the epithelium of the trachea and bronchi, except the epithelium of the bronchi involved in the pneumonic process, was intact; the delicate, ciliated margin could be readily seen. In contrast with the epithelial lining of normal appearance, the submucosa was greatly increased in depth, the blood vessels were injected everywhere, and an accumulation of polymorphonuclear leucocytes, fibrin, serum and red blood cells could be traced from the mucous membrane of the trachea near the site of the inoculation into the submucosa of the larger bronchi near the origin of the lung. From this point, the infection spread into the lung itself, and in several instances was clearly confined to the peribronchial and periarterial tissues, together with the alveoli of the lung in direct continuity with them. The inflammatory exudate involving the peribronchial and periarterial lymphatic trunks extended even to the pleural surface. Not infrequently a small fibrinopurulent accumulation was evident upon the pleural surface which seemed attributable to an extension from the parenchyma of the lung into larger structures.

These experiments, then, indicate that the infection of the lung was not caused by organisms introduced into the trachea, but followed the inoculation of the loose tissue of the submucosa, perhaps by way of the lymphatics, just as a Streptococcus lymphangeitis of the finger sometimes follows needle puncture.

Other experiments were performed to control the fate of bacteria introduced by insufflation into the lumen of the trachea just below the larynx without damaging the mucosa. Intratracheal insufflation without injury to the delicate tissues of the larynx or trachea is not an easy task, at least when rabbits are the subject of experiment. This is attested by the frequent occurrence of blood on the end of the catheter when it is withdrawn and by the occasional death of the animal during the operation from a clot which occludes the trachea. For this reason, in these experiments every precaution was taken to prevent such damage. A catheter with a blunt rubber end and lateral opening was selected to protect the guiding stylet. However, even with strict precaution, the results of the experiments were far from what had been expected.

[3] *Vide supra.*

[4] The Pathology of Influenza, M. C. Winternitz, Isabel M. Wason and Frank P. McNamara. Yale University Press, 1919.

[5] Blake and Cecil, *cf.:* Papers read before the Soc. of Exp. Path., April 19, 1919; Nat. Acad. of Sci., November 19, 1919; Soc. Amer. Bact., December, 1919.

FIG. 1.—A retouched photograph of the trachea and bronchi of a rabbit (cleared by the Spalteholz method) to show the lymphatics injected with India ink.

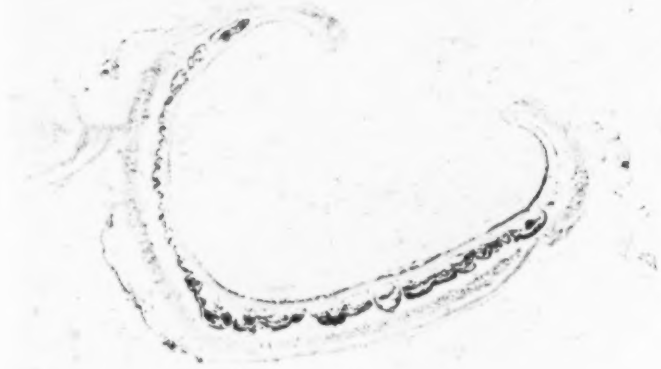


FIG. 2.—Cross-section of trachea just beneath the larynx. The rabbit was killed with chloroform and the lymphatics were injected with India ink. × 10.

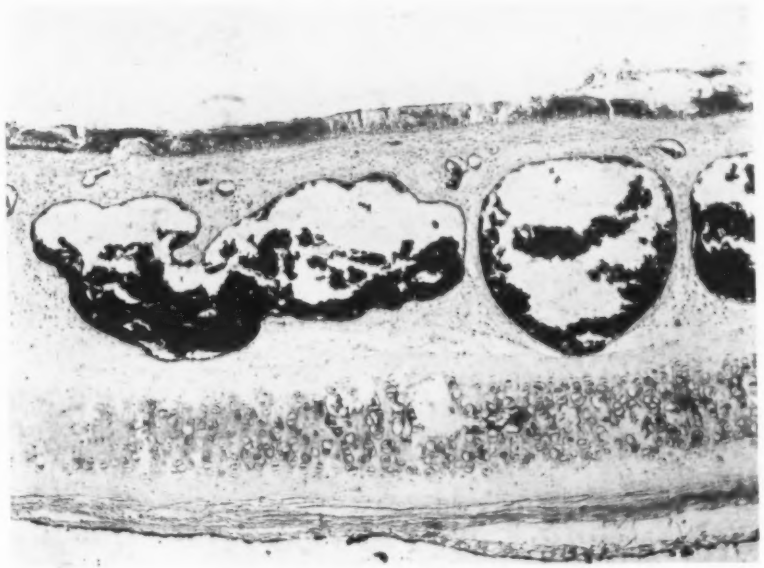


FIG. 3.—Higher power from Fig. 2.

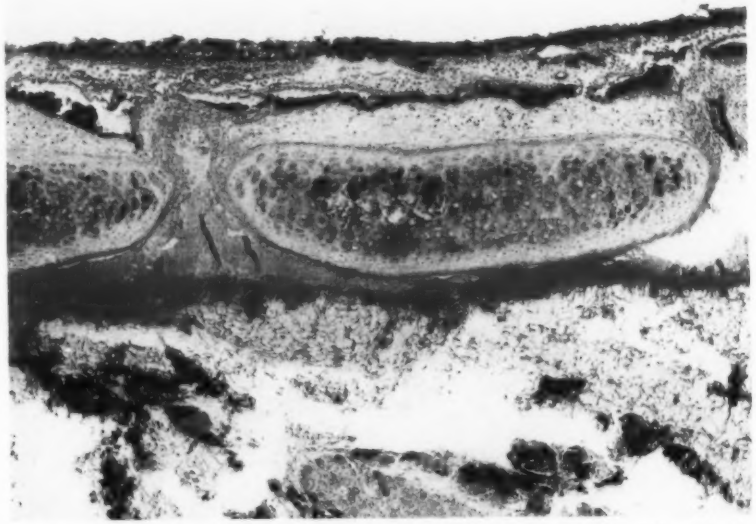


FIG. 4.—Longitudinal section through the trachea, showing the extension of the India ink in the lymphatics of the submucosa. × 55.

FIG. 5.—Cross-section of the trachea of a rabbit with India ink injection of the lymphatics of the submucosa. This section, taken below the bifurcation, shows injection of both bronchi. × 55.

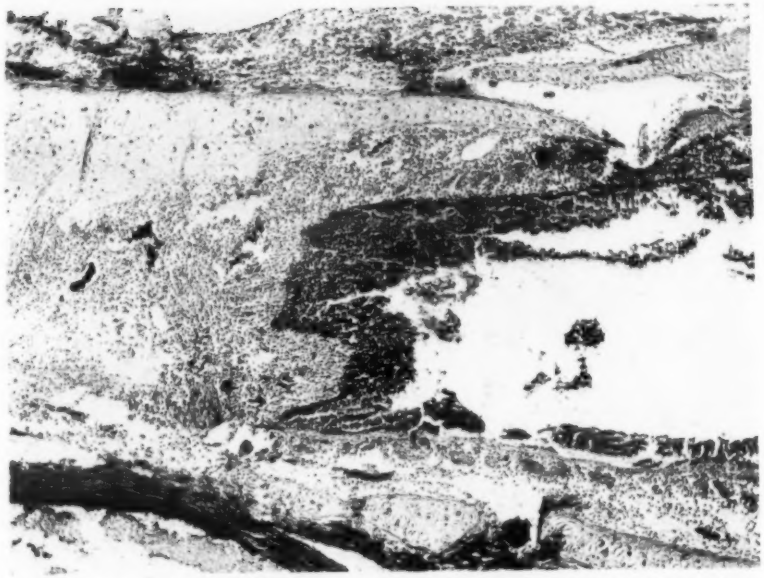


FIG. 6.—Section through the lung of a rabbit which had received an injection of India ink into the lymphatics of the tracheal submucosa just below the larynx. Masses of India ink are seen in the peribronchial and peritracheal tissues. × 55.

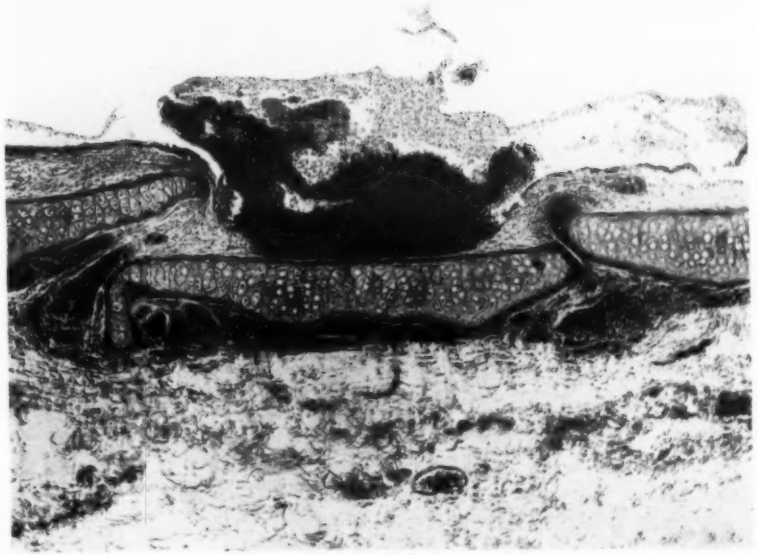


FIG. 7.—Section through the wall of the trachea of a rabbit which had received insufflation with virulent pneumococci. A plug of fibrin has formed at the point of injury. × 64.

FIG. 8.—Longitudinal section of trachea showing the inflammatory reaction in the submucosa. The injection of pneumococci was given by needle puncture through an area anterior to that illustrated. × 64.

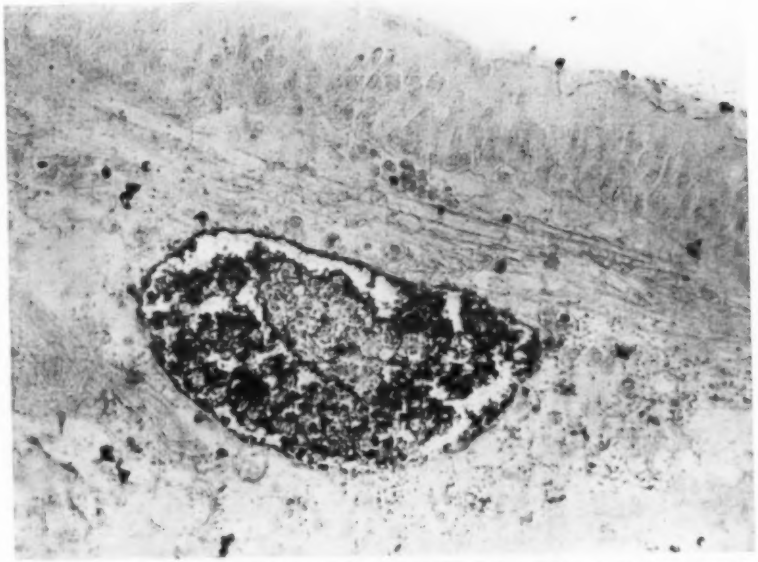


FIG. 11.—Gram stain of the trachea of a rabbit 4 days after the intratracheal inoculation by needle puncture. The lymphatics of the submucosa are distended by masses of pneumococci. Occasional organisms are found outside of the lymphatics in the submucosa. None are to be found in the mucosa or the lumen of the trachea. × 375.

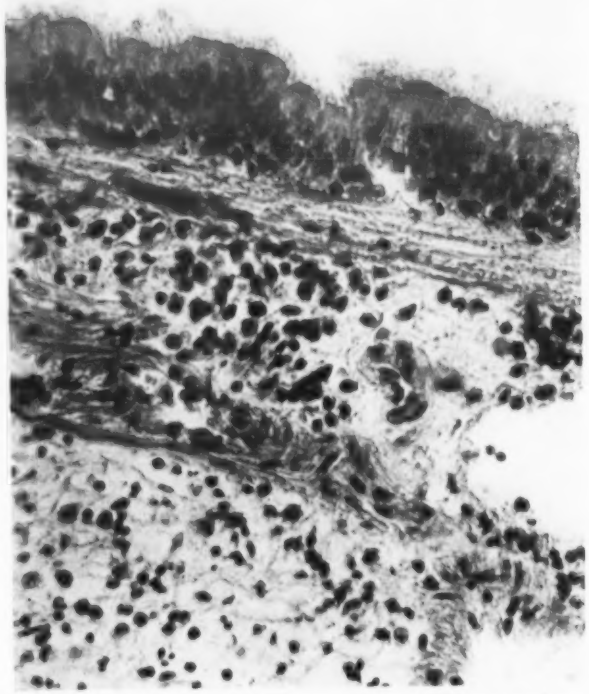


FIG. 9.—Higher magnification of the wall of the trachea. The ciliated margin is intact. The inflammatory reaction is confined to the submucosa. The point of injection was above this area, near the larynx. × 375.

FIG. 10.—Inflammatory reaction in the lung following the inoculation of the trachea by needle puncture just below the larynx. × 70.

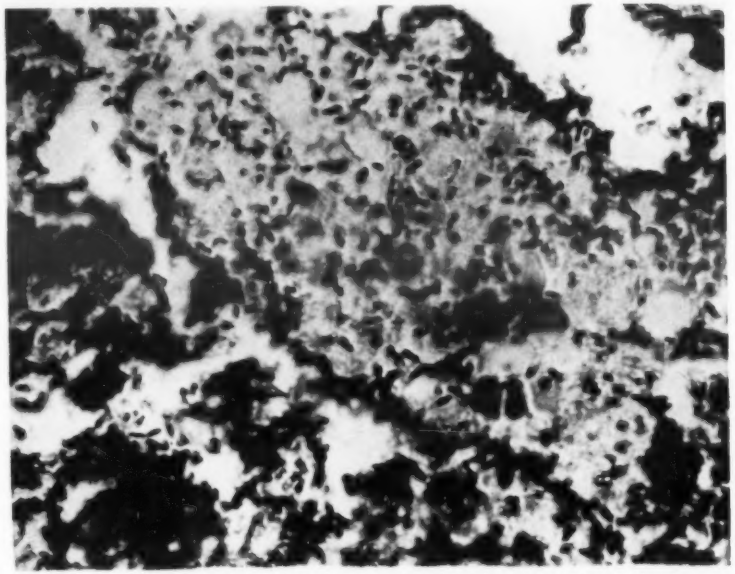


FIG. 12.—Higher magnification of a lymphatic shown in Fig. 11 to demonstrate the microorganisms.

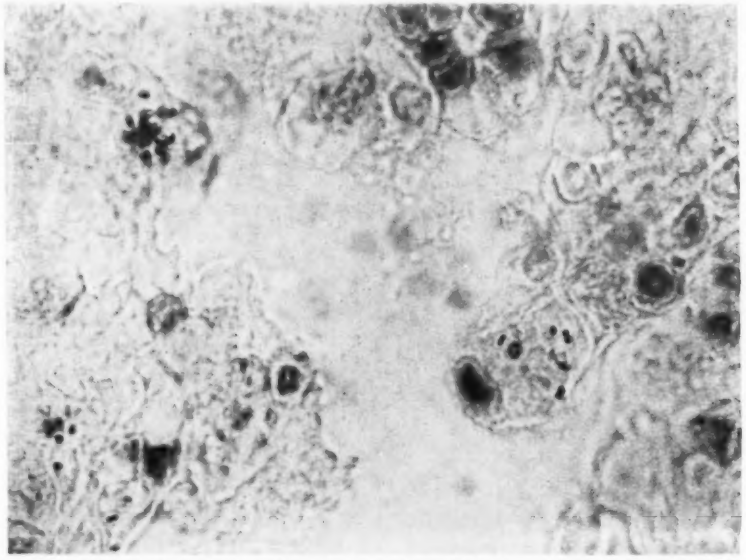


FIG. 13.—High magnification of a section of the lung. The pneumococci have passed down from the point of inoculation via the lymphatic system. × 1550.

In these animals the clinical course was not unlike that in animals inoculated by needle puncture. The gross anatomical findings also were identical. Mediastinitis, pleuritis and pericarditis all occurred, and while lobar pneumonia was not encountered, extensive lobular consolidation developed in many of the animals. The single point of difference between the animals inoculated by the catheter and those injected by the needle method was the absence in the former group of extratracheal inflammatory involvement in the cervical region. In no instance was there subcutaneous, intramuscular or peritracheal inflammation, but in all of the animals a minute lesion of the tracheal epithelium, usually just below the larynx, was seen grossly. It appeared as a small, grey, slightly opaque, friable nodule. The remainder of the epithelial covering of the trachea and larger bronchi was pale grey, translucent and occasionally slightly injected. Exudate in the lumen and marked injection of the lining membrane were found in the smaller bronchi only. Sections of the trachea through and below the point of injury, as well as those of the larger bronchi, all showed the same gross injection and thickening of the submucosal coat. Histologically, the inflammatory process in the trachea was confined to the submucosa; otherwise here, in the bronchi and in the lung, it was identical with that described above.

Occasionally, injection and even slight cellular infiltration was found in other coats of the trachea, but this was very inconspicuous. Only at one point was the lining of the trachea abnormal, and this point was the area of dam already mentioned. A few cells of the mucosa were here replaced by a plug of fibrin in which cells of the polymorphonuclear series were embedded.

This method failed to fulfil our purpose. We hoped that infection would not occur if the organisms were placed in the lumen of the trachea, but this, as we found, could be expected only if the operation caused no injury to the mucosa. Since in all of the experiments damage was done, the point of injury from the catheter served as a portal of entry for the infecting microörganisms. In fact, this series corroborated the previous one, inasmuch as the infection spread from the portal of entry through the submucosa to the thoracic viscera and involved the mediastinum, pericardium, pleura and lungs. Septicemia developed in these animals, but the point of entry of the organisms into the blood stream was not determined.

The primary object of this experiment was to demonstrate that bacteria introduced into the lumen of the normal trachea do not reach the lung. It seemed possible even that they would be mechanically carried to the oral orifice, or perhaps destroyed by the tracheal secretion, just as organisms are destroyed by the secretions of the mouth.[6] Although the experiments were inconclusive in this respect, we found that whenever animals were killed or died within 48 to 60 hours after inoculation, whether inoculated by needle or by insufflation, the lumen of the trachea was sterile. The wall of the trachea, however, contained bacteria.

[6] Bloomfield: The Fate of Bacteria Introduced in the Upper Air Passages. Bull. Johns Hopkins Hospital, 1919, XXX, 317.

THE LYMPHATICS OF THE SUBMUCOSA OF THE TRACHEA AND BRONCHI

The histological picture in the submucosa of the trachea and bronchi and in the periarteriolar and peribronchiolar alveoli of the lung suggested very strongly that the lymphatics of the submucosa of the trachea provided the pathway for the infection. However, in what way the infection spread from the submucosa of the trachea and bronchi to the pulmonary parenchyma was not clear.

It is well known that the submucosæ of the trachea and bronchi contain lymphatics, though little attention has been given to these structures as compared with that given the lymphatics of the lung. The latter have been thoroughly studied, and a brief review of our knowledge of them has recently been published by Miller,[7] one of the chief contributors to this field. Miller divides the lymphatics of the lung into two groups: the pleural lymphatics which drain directly to the hilum of the lung, and the deep lymphatics of the lung which also drain to the hilum and communicate with the lymphatics of the pleura by short branches whose valves point towards the pleura. The pleural lymphatics contain many valves. The deep lymphatics of the lung contain few valves, all of which are near and point towards the hilum. The lymphatics of the submucosa of the cartilage-bearing bronchi may be divided into two groups: Those beneath the mucosa and those in the peribronchial tissue. These two groups communicate by short branches in the intercartilaginous spaces. In the bronchi which have no cartilage, there is only one small group of lymphatics, while the alveolar walls have none. The lymphatics of the bronchi communicate extensively with the periarteriolar system, and a large trunk is located between bronchus and artery.

The injection of the lymphatics of the submucosa we found to be simple. A needle inserted beneath the mucosa almost invariably enters a large lymphatic, and with very gentle pressure a huge plexus is demonstrable, extending up and down from the point of injection. Above, it reaches the submucosa of the vocal cords and epiglottis. Below, it is very abundant as far as the bifurcation of the trachea and extends below the bifurcation of the trachea into the larger bronchi and even into the smaller, intrapulmonary, cartilage-bearing bronchi. The injection mass diminishes markedly at the bifurcation of the trachea and at each subsequent bifurcation of a bronchus, but if the injection is commenced at the bifurcation of the trachea or even lower down, a plexus as abundant as that in the submucosa of the trachea is demonstrable. The details of the extension of the lymphatics from the submucosa of the trachea and bronchi we have not yet completely determined; the subject is now under investigation. It may be said, however, that the plexus in the submucosa of the trachea anastomoses with another plexus in the peritracheal tissue, and that large lymphatic trunks are demonstrable in this vicinity. It is also clear that relatively large branches leave

[7] W. S. Miller. Studies on Tuberculous Infection, III. The Lymphatics and Lymph Flow in the Human Lung. Am. Rev. of Tuberculosis, 1919, III, 193.

the trachea and bronchi at the points of bifurcation, and there is some evidence that these anastomose with the periarteriolar lymphatics. Other smaller trunks pass directly to the mediastinum and, of course, to the glands in this vicinity.

It is necessary to assume that a short circuit occurs around the lymph glands at the hilum of the lung if the infection is carried to the lung by the lymphatics. It is known that there are few valves in the deep lymphatics of the lung and that these point toward the hilum. It is known also that the lymphatics of the submucosa of the bronchi anastomose with the peribronchial and periarterial lymphatics. A short circuit of the lymph glands at the hilum is actually provided by anastomosis of the lymphatics of the tracheal and bronchial submucosa with those of the periarteriolar and peribronchial regions. Unquestionably, other by-paths exist, but as yet these are not sufficiently defined for accurate description. However, it is pertinent that they provide paths by which infection may travel from the submucosa of the larger air passages to the lung.

The lymphatics of the submucosa of the trachea and bronchi, as we have now determined, are readily demonstrated when the tissues are stained by the Gram method after inoculation with pneumococci either by needle puncture or insufflation. The bacteria stand out prominently in the distended lymphatics of the submucosa, and although occasional organisms are seen outside of these structures, they are relatively inconspicuous. Furthermore, they never appear in the epithelial lining of the trachea or larger bronchi.

Conclusion

The submucosa of the trachea contains a rich plexus of lymphatics, prominent everywhere and devoid of valves. At the bifurcation of the trachea anastomosis occurs with similar plexuses in the bronchi, and this phenomenon is repeated throughout the region of the cartilage-bearing bronchi. At the bifurcation of the trachea, as well as of the bronchi, there is drainage to the lymph glands and anastomosis with periarterial and peribronchial lymphatics. When the lymphatics are injected, the larger portion of the material is diverted at these bifurcations, but continuity of the lymphatic system in the tracheal and bronchial submucosæ is demonstrable.

Pneumococci introduced by needle puncture through the skin into the lumen of the trachea or by insufflation, provided the insufflating catheter damages the epithelium of the trachea, spread by way of the lymphatics to the lung. The lymphatics of the submucosa of the trachea, then, afford a direct pathway of infection to the lung. Although this lymphatic system provides a pathway for infection, it may also serve as a protective mechanism against pulmonary infection, for the drainage of the submucosa of the trachea and bronchi is largely diverted as the lung is approached to the protecting regional lymph glands.

GERMAN NUTRITION, 1914-1919

By Cleon C. Mason,

Major, Sanitary Corps, U. S. A.

When, on the 4th of August, 1914, England declared war on Germany it was a foregone conclusion that a blockade would at once be established, and a question thrust itself upon everyone who had any knowledge of German economic life: Could Germany hold out through a long war if cut off from her considerable imports of food and fodder? The question of a nation's food supply during war is such a problem that for its full appreciation and solution the politician, the political economist, the statistician, the physiologist, the farmer, the geologist, and the housewife must each be called upon to contribute his or her share of knowledge. With the question clearly before them, the German authorities at once proceeded in a typically German manner to attack the problem. The result was a large committee, which eventually, under the leadership of Eltzbacher, produced a volume called " Die deutsche Volksernährung und die englische Aushungerungsplan." This volume was Germany's answer to the blockade.

The volume sets out to show the German food requirements, first per capita, and then translates this into national needs of millions of tons of protein and milliards of calories. The national consumption is analyzed into home produced and imported, accurate estimates and percentages calculated as to protein and calories coming from abroad, and finally the work points out that the German nation can hold out indefinitely, provided the advice given is followed. There is every reason to believe that the book is a serious attempt to solve the most difficult of all the questions which the Germans faced, and had the German Government heeded to a greater extent the ideas advanced there seems to be good reason for feeling that the " Aushungerungs " plan would have failed.

The essential data in the memoir are to be found in the tables, which are attached, a study of which will help greatly in an appreciation of the food problem in Germany. Dr. Waller, of the University of London, in his preface to the English translation of the volume, has summarized these tables as follows:

Germany used of protein in 1912-1913	2,261,900 tons.
Germany can live upon	1,605,000 tons.
Home resources normally produce	1,554,000 tons.
Home resources can produce	2,022,800 tons.

This table, translated into per capita per day consumption, a form more comprehensible to the average person reads:

Protein consumption, 1912-1913	93.0 grams.
Minimum physiological requirement	64.0 grams.
Home resources normally produce	62.5 grams.
Home resources can produce	81.5 grams.

This table, as will be noted, is based on a per capita per day basis, and not on a per *man* basis. For all ordinary purposes the total population (men, women, children) multiplied by 0.80 will give the *man* population. The Interallied Scientific Commission of Food sets down the following factors as being official in the countries named for the calculation of man population:

For the United States	0.84	For France	0.85
For the United Kingdom	0.835	For Italy	0.826

The German factor, as calculated by the Germans, varies between 0.7625 and 0.8085, in either case being a much lower figure than any quoted above, due to the larger child population of Germany. On the per *man* per day basis the German data show that:

Protein consumption 1912-1913 was	116 grams.
Minimum physiological requirement is	80 grams.
Home resources normally produce	78 grams.
Home resources can produce	102 grams.

It will be noted that the protein requirement is set rather low, not only as regards the German consumer, but as regards the scientific consideration involved. This will be referred to later.

The total calories required received the same careful attention and the data, scientific and statistical, resulted in the following tables:

Calories consumed, 1913-1914	90.42 billions.[1]
Physiological requirements	56.75 billions.
Normal home production	57.68 billions.
Home resources can produce	81.25 billions.

This table translated into daily consumption reads:

	Per man	Per capita
Calories consumed, 1913-1914	4779	3642
Physiological requirements	3000	2287
Normal home production	3577	2727
Home resources can produce	4295	3274

This showing in relation to calories is much more promising than the protein showing.

The amount of food imported prior to the war is shown in the following paragraph from the German Memoir, page 74, English translation:

Our total consumption of all foodstuffs before the war amounted to 2,261,900 tons of protein, 2,581,000 tons of fat, 12,913,000 tons of carbohydrates, and 88,649 milliard calories came from abroad. We therefore had to thank the foreigner for 26 per cent of protein and 20 per cent of calories.[2]

From a study of the above figures the deficit is obvious. However, on the total nutrients there is a deficit only in relation to the standards of consumption; the real needs are more than met. In the case of protein there is a deficit, not only in relation to consumption, but in relation to needs, and that on the basis of the protein need which it appears is set too low. One of the causes of the especial shortage in protein is to be found in the lack of foreign fodder, it being impossible for Germany to trade her protein-free sugar for protein-building foods.

[1] The German milliard = 1000 millions or 1,000,000,000. The German billion = 1 million millions or 1,000,000,000,000.

[2] See attached table, Number I (Page 75, Eng. Tr.).

Such, very briefly, was the situation in 1915 as seen through the eyes of the best men in Germany. One must look further and see how it was planned to meet the deficit caused by the blockade and then, to get a picture of the whole, must consider what happened as the war progressed in order to appreciate fully the condition found in Germany in January, 1919.

The problem which the German nation faced was one of making its income meet its needs. Inasmuch as consumption had been in excess of needs it became necessary to reduce the consumption, which, if done wisely, would result in the solution of the problem as it related to calories, for the normal home production of total food value was greater than the national need. But to meet the protein deficit, the country normally producing only 97 per cent of the low estimated needs, was a serious problem. Not only must the 3 per cent be overcome, but enough more produced to allow for the inevitable losses occurring in handling. From a physiological standpoint the protein deficit was further complicated by the fact that the body has no protein reserves, but lives a hand-to-mouth existence in this relation. The fat and small carbohydrate reserves, when supplemented by even an inadequate diet, can be made to last for surprisingly long periods. Long before these reserves are exhausted there is a genuine call for protein.

One of the first procedures advised was an immediate reduction of the live stock, and especially of the hog. Stock consume mostly vegetable foods, convert it into meat and fats which are then food for humans. Certain animals can eat the foods which man cannot consume, *e. g.*, cattle and sheep will maintain themselves on pasturage and straw or hay, foods entirely useless to man, and these animals will convert this inedible material into a food useful to man, either as milk or as meat. On the other hand, the hog is not an animal that can live in such a way. A hog must be fed upon materials which will also make human food. The hog question is clearly shown in the following statement of a hog's converting efficiency:

Food required to fatten	Protein, 45 kg.	Calories, 1,327,000
Fat hog produces	Protein, 11 kg.	Calories, 607,750

Therefore, in the fattening process we are able to recover from the hog only 24.4 per cent of the protein given and only 44.3 per cent of the calories supplied and there is good reason to believe these figures are high. Unless the hog is going to be fed entirely from the foods not edible by humans it would be wiser to eliminate him. This problem of the hog as a competitor for human food received a great deal of attention in Germany through the war, and the fact that in

1914 there were	26,000,000 hogs, and in
1919 there were	8,000,000 hogs

shows that beyond a doubt the situation had become serious. This great reduction in the stocks of pigs was not, however, the result of the advice given to reduce the number. Had the reduction been carried out scientifically, the meat carefully cured and stored, the country at large would have fared better. As it was, with every change in crop outlook the attitude towards the hog changed. To have ordered the entire

nation to slaughter all the hogs would have been an impossible measure, so the situation took a natural course. When it looked as if there was going to be a shortage of food for the hog, the people began to slaughter, and for a period there was a great plenty of meat; then followed a period when there was less, and this alternation kept up until the hog stock of Germany became too low to permit of any further reduction. It is interesting to note that each successive period showed a smaller and smaller meat supply. The German policy in relation to the increase of the protein supply may be quite simply stated: "Do not feed an animal grain which you could eat because you must allow the animal a 75 per cent profit. Eat the vegetable protein yourself and save the animal profit."

The solution of the problem lies in a broadening of the vegetable basis of the human food supply, and a simultaneous slight contraction of its animal basis. A general principle may be deduced that when the vegetable basis of the human food supply suffers contraction, the amount of vegetable food for direct human consumption must be immediately increased. If a sufficient increase cannot be effected because the food of animals has been composed largely of grass and hay, which are not suitable for human food, then part of the meadowland should be converted into ploughland so that the requisite vegetable calories may be secured for human nourishment by increased cultivation of grain and potatoes. In any case it is a completely mistaken policy, when the general vegetable basis of the food supply has undergone contraction, to reduce the direct human consumption of vegetable foodstuffs for the sake of producing animal foodstuffs. If a workman, on finding that the amount of vegetable calories available daily has been reduced from 7000 to 5600, seeks to reduce his consumption of animal calories from 2000 to 1000 in order that he may have 4000 calories for conversion into animal food, he will obtain from such conversion only 920 calories, and his total daily food supply will therefore amount to 1920 calories; this is absolutely insufficient, and he will not be able to continue his daily work without using up his physical capital, losing heavily in weight, and eventually falling into disease. By raising his direct consumption of vegetable food to 2500 calories per day, on the other hand, he will be able to obtain the same number of calories as before, and even a little more. But this method, of course, can only be effectively applied if the cattle stocks of the country are reduced to such an amount as can be properly fed with the diminished supply of fodder. Otherwise the vegetable calories used for fodder will be partly or wholly wasted, instead of undergoing conversion into their full equivalent in animal calories.

A practical illustration will make this clear. Suppose there are two families, A and B, which are exactly similar in circumstances, but pursue opposite food policies during the war. Each of these families consists of five members, and possesses a plot of land which yields annually 2500 pounds of bread grain and 7000 pounds of potatoes; each family keeps a goat, which lives on grass, hay, and kitchen waste, together with two pigs every year, which are brought each to a slaughter weight of 300 pounds. The grain and potatoes grown by each family are not by themselves sufficient for the feeding of the family and the fattening of the pigs, and each family therefore has to buy 500 pounds of bread grain and 1500 pounds of potatoes every year; so that altogether each family has 3000 pounds of bread grain and 8500 pounds of potatoes at its disposal. Each family consumes 1500 pounds of bread grain and 2500 pounds of potatoes directly, and uses the remaining 1500 pounds of grain and 6000 pounds of potatoes for the fattening of the two pigs to a slaughter weight of 300 pounds.

The outbreak of the war makes the purchase of grain and potatoes impossible, and each family is compelled to rely exclusively upon its own production of 2500 pounds of grain and 7000 pounds of potatoes. Family A resolves to keep only one pig; this one pig is fed, as in time of peace, with 750 pounds of grain and 3000 pounds of potatoes, and brought in this way to a slaughter weight of 300 pounds as before. For its own direct consumption family A has therefore 1750 pounds of grain instead of 1500 pounds as previously, and 4000 pounds of potatoes instead of 2500 pounds. These quantities are more than sufficient, so that a part of them can be supplied as additional fodder to the pig, which is thereby further fattened to a slaughter weight of 350 pounds. Family A by this method secures a more ample supply of vegetable food than in time of peace, together with an adequate, though diminished, supply of animal food.

Family B pursues an opposite policy. It resolves to maintain two pigs, as in time of peace, and to divide the deficiency of 20 per cent equally between men and pigs. The hard working members of the family lose weight, and the pigs do not grow fat. The fodder supplied to them is wasted for the most part in their mere maintenance, and they put on very little meat. When the fattening period is over and the appointed supply of fodder completely consumed, it is found that the slaughter weight of each pig is only 150 pounds. Family B therefore has only 300 pounds of meat as against 350 pounds secured by family A; and, moreover, the quality of this meat is very much inferior to the quality of that secured by family A. One kilo of lean meat yields only 1000 to 1500 calories, whereas 1 kilo of fat pork yields 4500 and pork fat ("speck") as much as 7000 calories per kilo. The single pig maintained by family A has therefore at least three times as much nutritive value as the two pigs maintained by family B.

The father of family B does not perceive that his policy has been radically wrong. Disputes have arisen in the family because the housewife has occasionally given a handful more potatoes to the hungry pigs or a handful more bread to the hungry sons than was provided for in the scheme of rationing. The father considers that such irregularities are the real cause of his failure, and resolves therefore to pursue the same food supply policy in the coming as in the past year, but to enforce it with more energy and strictness. The energetic prosecution of a mistaken policy does no good; the previous difficulties remain and the discontent in the family increases.

Germany has pursued the same policy as family B, and all her food supply difficulties arise from this fundamental fact.

She has aimed at maintaining her large stock of cattle undiminished through the war, despite the stoppage of concentrated fodder imports; whereas she ought to have adjusted the stocks of cattle to the available fodder supplies by means of a scientific reduction. As a matter of fact, the stocks have been allowed to attain dimensions never reached in time of peace. They numbered 21,828,783 head on June 1, 1917, as against 20,994,341 head on December 1, 1913, although it is true that the number of cows shows some diminution. At the beginning of the war an attempt was also made to maintain the pig stocks at the level of peace time, and although reduction was afterwards undertaken, it has not been sufficient to allow proper feeding of the stocks which have been kept. The authorities have worked directly for the maintenance of excessive cattle and pig stocks by means of slaughter prohibitions, excessive promotion of breeding, promises of official supplies of concentrated fodder, and reduction of meat rations. The result is that large quantitives of vegetable food and fodder stuffs have been wasted in the mere maintenance of cattle and pigs, without any production of meat or fat. The ill-fed cattle have deteriorated considerably in quality, and there is less meat, fat, and milk for the public than would have been obtained from the same quantity of fodder if fed to a smaller number of cattle. Not only so, but the bread and potato rations for human consumption have been reduced in order to make grain and potatoes available for the maintenance of cattle.

Economy in bread and potatoes has been preached, although in reality true food economy would require the fullest possible direct human consumption of bread and potatoes up to the physiological point of satiation. Economy in the use of bread and potatoes, in order to use them as fodder, means an enormous waste of food supplies. This waste must be estimated at many million tons yearly, since not only are foodstuffs withdrawn from direct human consumption, but fodderstuffs, unsuitable for human food (hay, roots, beet-slices, etc.), are wasted in the maintenance of cattle, instead of being profitably used for their fattening. The result is that Germany, like family B, suffers from shortage of vegetable and animal food alike. If she had pursued the same policy as family A, and had scientifically reduced her cattle stocks, she would now have an ample supply of vegetable food and much more animal food than she actually has. Nor would her cattle stocks be in any serious danger. In Germany, unlike England, the vegetable basis of the food supply is broad enough to allow under all the circumstances not only an ample supply of vegetable food to the public, but also the proper fattening of a considerable part of her cattle stocks, without any import being required. The policy pursued by the German authorities has considerably accentuated instead of counteracting the effect of the British blockade. A complete break must be made with this mistaken policy. The authorities must be brought to see that the present is no time for the hoarding of cattle with a view to the *post bellum* period.

Finally, there were powerful political reasons for an immediate comprehensive improvement of food conditions. The widespread discontent among the German people is due mainly to the dislocation of the food supply, and will disappear as soon as this dislocation is remedied.[3]

But for all the elaborate plans, in spite of the continual assurances that they were getting enough, in spite of the rigid food control and food rationing, something was wrong. On paper, at least, everyone was getting all the calories he needed, but he was hungry all the time. Throughout 1915 things ran smoothly, due to the popularity of the war, the patriotism of the people and their perfect confidence in the outcome. Then came the poor crops of 1916, and from that time on things have gone from bad to worse. A typical example is shown in the attached chart which gives by six-month periods from July 1, 1916, to January 1, 1919, the complete figures for the food allowed for one person by the prescribed ration. The second part of the chart contains a *résumé* showing the content of the ration, by periods, in fat, protein, and carbohydrate, and its caloric value. A careful study of these figures will show something of the seriousness of the situation. With an average caloric value of about 1500, the ration probably represents less than 1000 calories of value to the body because of the low digestibility of most of the foods. The bread as supplied, in the course of digestion loses 40.3 per cent of the nitrogen and 14.8 per cent of the total calories, and the "Steckrüben" supplied so freely as a potato substitute in 1916-1917 loses 66 per cent of the nitrogen content and 22 per cent of the caloric value. Nor was it possible to improve the diet, because the only foods available were the vegetables of a similar character, with high cellulose content. There was, to be sure, a great deal of food which could always be purchased at high prices through illegal methods, but this food never got into the hands of the poor, the people who needed it most.

The policy of rationing the food caused a great deal of trouble. Any attempt to bring a large group of people under one diet will always result in grave inequalities. In his report of December, 1917, Rubner refers to this situation with some bitterness. He said:

The more thoroughly we consider to-day the conditions of national nourishment in their effects upon health, the more the conclusion is forced upon us that the blockade and embargo compel us to get along with our own food products, but that the real basis of the injurious effects of the diet to be traced lies merely in the distribution of the food, which works disadvantageously for individual sections of the nation and certain groups of persons. In the very beginning we pointed out that the distribution between city and country has turned out to the disadvantage of the city. It was not necessary to change the composition of the diet of the rural districts and it has in many sections, where the diet was formerly very poor in meat, become richer in meat, due to the establishment of the Imperial Meat Bureau. . . . . It is, however, clear that the very principle of economy itself is violated by any system of rationing, and that such a system in and of itself, if it is made as simple as possible, comes into conflict with the attempt to supply the population with proper nourishment. The amount of nourishment required depends upon the mass of a human being's body and its functions, which vary in both large and small cities according to the climate, clothing, season of the year, calling, habits, sex, age, psychic differences, etc., and which again vary for

[3] G. Oetelshofen: Kölnische Zeitung, October 14, 1917.

each individual with every day of his life. The natural amount of nourishment taken in is in every case regulated by requirements, as noted by sensations of hunger and of repletion. In individual cases these sensations, like every other function, may vary from the normal, being either decreased or increased in an unhealthy manner. The nourishment desired is closely adapted to the nourishment required, hence the conditions of balance often maintained for years in an adult. To-day, however, we have come to a rationing of foods to so large an extent that the ration alone gives the bulk of the nourishment, and permits the free purchase of other things only to a limited and inadequate extent. The present plan attempts to nourish with little variation, infants, children, pregnant women, nursing mothers, persons working fairly hard, and persons engaged in the hardest kinds of labor, with an amount uniform for all, with the same kind of food for each class, and through very limited supplies given out at very short intervals and throughout the entire Empire. Such a nation-wide system of food distribution as compared with self-regulation does not lead to economizing, but to an excessive consumption of supplies.

The food system behind the front recognizes no social distinctions according to needs, no individual prerogatives, neither the particular requirements of men and women nor the trade distinction between quite heterogeneous elements, and in the case of adults; no distinction of age. The classification into workers and non-workers takes from the latter every chance of bettering their condition. The amount of food allowed by a food ticket is purely a mathematical quantity, of interest as such when considered from the standpoint of national economy or physiology, but which in its practical application works a grave injustice. It is a correct estimate, provided the holder possesses the average weight of the nation; for those underweight it is too much, for those overweight it is too little, nourishment. Families with young children have a better chance of evening up inequalities than a family with grown children, while elderly people who usually live alone fare very badly. The artificial distribution as carried on at present can never provide proper national nourishment.[4]

There is a very definite causal relationship between the inadequacy of the rationing system as worked out in Germany and the government policy of price fixing. In normal régime, where the laws of economics, competition, etc., are allowed free play, all prices seek a level that is just and fairly constant. In setting the maximum prices for farm produce the government had in mind only the proper alimentation of the nation. Due to the severe lines of the ticket system for procuring food, there arose a demand in certain places for certain foods, and this demand in turn led to the offering of greater prices than the prescribed maximum, and out of this situation, due partly to the low maximum set and partly to the weaknesses of the rationing system, developed the entire system of "Schleichhandel." The government made one grave mistake. The price of farm produce was set, but no effort was made to regulate the price of labor, the price of machinery, nor the price of fertilizers. The farmer saw men going to the munitions factories and receiving a much larger wage than ever before paid in Germany; in addition certain rich men were making huge war profits, these things leaving the farmer able to collect only his rather low maximum price, due to the price fixing policy. The only natural outcome was the extensive illegal dealing which grew to large proportions before the end of the war. This fact accounts for a great deal of the shortage in such items as butter, fats, milk and meat.

[4] Unpublished report of Rubner, December 20, 1917.

The ultimate outcome of the entire situation was a large number of grave discrepancies in the national nutrition, wherein it was almost impossible for the poor to get proper food, while the rich had all they wanted. The actual diet allowed by ticket was not enough for human subsistence. A number of German scientists worked on this very problem—Rubner, Neumann, Bach, and Fr. Müller. Neumann,[5] working in Bonn, has supplied the writer with a vast amount of extremely valuable data and charts. In Bonn, from July 1, 1916, to July 1, 1917, the average value of the foods supplied on ticket was:

Protein	41.00 grams.
Fat	20.00 grams.
Carbohydrate ...	280.00 grams.
Calories	1510.00

Nor was Bonn the only city to find that the ticketed supply would not meet human requirements. In the summer of 1916 the supply was:

In Berlin	Protein	36.3 grams.	(Loewy.)
	Calories	1312.0	
In Wiesbaden...	Protein	43.6 grams.	(Arnold.)
	Calories	1547.0	
In Munich	Protein	45.9 grams.	(Köhler.)
	Calories	1709.0	

While living on the rationed foods for a period of seven months Dr. Neumann records a total weight loss of 37 pounds, or 18.5 kilograms, the beginning weight being 76.2 kilograms and the end weight being 57.6 kilograms. During the period of the observations Dr. Neumann was engaged in active work at the university, and during the last two months went into the fields and did the work of a farmer in addition to evening work at the university.[6]

This condition of loss of weight has been true all over Germany. If the average weight loss has been to a degree approximating that recorded above, then it is easy to figure what the national loss has been, not only of weight, but along the lines of efficiency and ability to work. There is no reason to believe that the average loss per man was anywhere near the figure set by Neumann, for the reason that a great deal of food moved through channels other than the official ones; probably between 25 per cent and 33 per cent of all food in Germany was sold through "Schleich-handel." This fact enters into all considerations of the nutrition of the masses during the war, and must always be borne in mind in following any discussion of the food. What the German was allowed on ticket and what he really managed to obtain were quite different things, probably spelling the difference between a starvation diet and a living one.

Taking into consideration the low digestibility of the foods supplied it cannot be assumed that the rationed foods actually delivered to the body more than 1000 to 1100 calories daily. It needs no scientific proof to show that a hungry person needs more than 1000 calories daily, to satisfy his needs.

[5] Die Kriegsernährung in Bonn im Winter 1916/17, u. s. w. von R. O. Neumann.

[6] See Table IV (Neumann).

From a great deal of experimental work it is well known that the average person requires between 30 and 32 calories per kilogram of body weight, this when he remains quietly in a room and does no moving about. This figure is known as basal metabolism, and any estimates of a person's food needs must take this figure as a basis to which all others are added. Hence a man weighing 60 kilograms will need for his basal requirements about 1860 calories daily delivered to the body. If he were supplied with foods of the best quality, the gross need would be for 2065 calories in order that the losses of digestion might be compensated. With the rationed diet there is no doubt but that the Germans, as a nation, lost considerable weight. When a person begins to lose weight the loss consists of those things lacking in the diet, either from the fat layer or protein, probably both if the insufficient diet is maintained for sufficient time. By these losses the human being reduces the mass of the body, arriving at a new scale of weight and therefore a new level of nutrition. But this attempt at adaptation can only proceed to a certain limit; from animal experiments and observations on humans it is known that starvation ensues when the body weight which was previously normal reaches a half.

The data furnished by Neumann in his experiment upon himself throw some interesting light upon the problem of body requirements and the relation to weight losses. Neumann lived for seven months on the following ration:

Protein	45.00 grams daily.
Fat	18.90 grams daily.
Carbohydrate	286.00 grams daily.
Calories	1546.00 daily.

During the period of the experiment he lost 18.5 kilograms or 24.4 per cent of his body weight. Towards the end of the experiment the rate of loss had become less rapid. From this it can be reasoned that the calories supplied were only 75 per cent of the amount necessary to maintain the body, that to have done the same work and to have held the beginning weight the body should have had about 2060 calories. Unfortunately, we have no data relating to the nitrogen losses during this work.

The question of the nitrogen metabolism is of especial interest since the lack of protein was, throughout the war, one of the distinguishing features of the diet. The much discussed question concerning the amount of protein necessary for a human was again revived in Germany, this time with a peculiarly human interest. In discussing this point at a conference in January, 1919, Rubner said that the grand experiment was far superior to 70 million rabbits. Bach,[7] working in Bonn, found that a nitrogen balance could be maintained on a protein turn-over of 0.92 gram per kilogram of body weight. This figure was the result of a long series of experiments on himself and four others, all living on the rationed diet. For a man of 70 kilograms weight this calculates to a protein need of 64.4 grams daily, a figure strikingly near that set by Chittenden.[8] However, the consensus of opinion as voiced by the German scientists is that as soon as possible the people will get back to a higher level of protein metabolism. The war diet was forced upon the people by want, best illustrated by the loss of weight recorded from all parts of Germany. In a conference Rubner referred to the need of protein as follows: "No human being can perform work if the muscles are insufficient. One fact is very interesting, *viz.*, that the loss of protein, due to the very small quantity of this substance contained in the alimentation of the people, can follow a steady course and may continue for quite a length of time before the effects become noticeable. In order to bring the population back to its old standard small amounts of protein are of no avail; protein must be given in increasing doses. Food containing protein will be able to rebuild the nation as a whole." And through all the German writings runs a rather hazy idea; no one is willing to predict, yet all express, a grave fear for the future results.

Another interesting fact has been noticed, for some years known in relation to animals, but owing to the lack of opportunity, not followed up in the case of humans. In animals it has been found that, after starvation or undernourishment has been allowed to proceed beyond a certain point, it then becomes increasingly difficult for the animal to maintain a protein balance even when fed relatively enormous amounts. This fact has been reported in many instances in Germany in which persons who have lost weight almost to the limit are frequently unable to establish a balance even when fed as much as 100 grams of protein daily.

The low protein diet has led to some other results. It has often been noted that many persons suffering from malnutrition were anemic. This would lead to the belief that the body, in order to prevent its own death, can set great limitations as regards the renewing of organs, above all else the formation of new blood, the reconstruction of tissues, and the healing of wounds. This is most strikingly shown in the great number of reports which have referred to a common condition found in women, suppression of menstruation for long periods, and among men to the less frequent report of testicular atrophy and a greatly decreased sexual libido. Perhaps there is some connection, after all, between the rapidly declining birth-rate in Germany and the low protein diet.

In addition to an actual loss of weight most of the German observers point to other results, loss of efficiency, morale, etc. They point to widespread slowing up of national industry, loss of endurance, the ease with which persons become fatigued, a great tendency to forget, and among professional people a loss of initiative. Most of these results are not physical but mental; in fact the entire German nation to-day is undergoing great psychological changes, unrest, riot, and revolution being rampant. That this is solely the effect of empty stomachs and hunger pangs, as the German writers would have us believe, hardly seems logical, but that hunger has played its part goes without saying.

The question of the bread supplied the German population is worth some consideration.[9] In peace time the bread fur-

[7] Bach: Berliner klin. Wchnschr., 1919, No. 6.

[8] Chittenden: Physiological Economy in Nutrition. 475 pp.

[9] Rubner: Report to the Public Health Department, 1917.

nished more than one-third of all the calories in the average diet. Of every 100 calories there were:

Peace times, in bread.....36.9 calories.
Fall, 1917, in bread.....51.2 calories.

In fact, bread and potatoes constituted the bulk of the ration and it was not everywhere that even these articles were fully supplied. In order to combat the increasing grain shortages the flours were ground out to 94 per cent. This was done in order to supply the people with bulk. It is a question whether the practice did in the end result in economy or loss of good food materials. The chief difference between a low percentage flour and a high percentage flour is the cellulose content. The grain, consisting of the germ, the endosperm or the kernel, and the bran, the outer envelope, consisting of cellulose and mineral salts, shows the following approximate proportions of the parts:

Germ ..... 1½ per cent.
Endosperm ..... 85 per cent.
Bran ..... 13½ per cent.

In milling, the process tends to grind out, as far as possible, the cellulose. The cellulose is the chief constituent which enters into the bulkiness of bread.

Two factors largely determine the digestibility and absorption of foods in the process of digestion: The first is the bulk; the second is the cellulose content. The bulkiness of vegetable food interferes with digestion in two ways. The digestive juices have difficulty in penetrating such a mass so that the conversion of the constituents into products capable of absorption is apt to be quite inefficiently carried out, and the large mass has a tendency to hasten the intestinal peristalsis, the contents of the gut are thus pushed forward too rapidly; and even were digestion more complete, the absorption could not keep pace with the food movement. In this connection it is interesting to note that the herbivorous animals have relatively much larger intestinal tracts than the carnivorous animals. Hausemann, working with the Russians, confirmed older data to the effect that the Russian had a longer intestine than most other of the Europeans, not in the sense of a race characteristic, but as an adaptation to the diet which was hard to digest, such a diet as the Russians live upon.

The presence of cellulose is the second great factor in the retardation of digestion and absorption. In the case of meat, the nutritive constituents are held in tubes, composed of gelatin, which readily digest; in the case of vegetables, the starch is contained in cubical compartments with walls of cellulose. Cellulose is a carbohydrate, belongs to the class of polysaccharides, and is especially characterized by its extraordinary insolubility. From this it can be seen that the presence of cellulose influences digestion and absorption in several ways. It not only has little or no food value of itself, but it prevents the access of digestive juices to the mass of food in the stomach, and it prevents the juices penetrating to the individual starch cells. Further, by increasing the mass to such an extent it has a tendency to stimulate the intestinal movements and hasten the progress of the food.

Romberg has worked out the following table of composition and percentage loss in digestion of protein in four grades of rye flour. Grade No. 1 was made from the endosperm only, and was pure white; grades No. 2 and 3 had increasing quantities of bran included; while grade No. 4 was made from the whole grain.

	Protein content Per cent	Loss in digestion Per cent	Protein absorbed Per cent
No. 1	7.43	22.00	5.80
No. 2	11.59	28.60	8.28
No. 3	17.28	30.50	12.01
No. 4	16.84	43.00	9.60

As far as the protein content is concerned, mixture No. 3 is the most efficient as a human food. Unfortunately, the author does not state what percentage of milling each grade represents, but it is clear that the whole meal bread is not so good as the other grades.[10]

It is evident that in the milling of flours there comes a point in the grinding out where the law of diminishing returns begins to play; that is, there is a percentage at which the milled flour is the most efficient food deliverer. That the flour must not be milled to too high a percentage is evident, for the great cellulose content will not only hamper the digestion of the protein, but will interfere with the digestion of the carbohydrate. In the case of the German flours during the war, especially when the one great problem of the diet was protein, the mistake of grinding out to 94 per cent is quite obvious. Not only was the bread actually less efficient as a food, but by milling to a lower percentage the bran would have been used as fodder, thus putting it to a useful purpose instead of allowing humans to eat it with no good to them; rather it did actual harm, in that it caused, indirectly, a portion of the available protein to be lost.

These facts were all well known to the German scientists; in fact, they advised that rye be ground out to 70 per cent only, but here again the authorities could not or would not follow the advice given. To have ground to 70 per cent instead of 94 per cent would have meant a loss of about 20 per cent of the bulk of the flour, and when it was a case of filling stomachs little attention could be paid to the quality. When one realizes that the Germans had been importing annually 2,263,654 tons of cereals, about 30 per cent of their total consumption, the necessity of increasing the quantity is apparent. Nor did the lowering of the quality of the flours stop at the milling process, often it contained a number of foreign substances, wood pulp, weed seeds, straw, etc.

All this seriously affected the fodder situation, which in turn had a direct influence on the milk, meat, and fat supply. Attempts to increase production were not successful because labor was extremely scarce, fertilizers could not be had, and the number of animals for draught purposes, due to the shortage of fodder, was materially decreased.

As already stated there was a great deal of dissatisfaction created throughout all Germany by the evident inequalities

[10] Romberg: Arch. für Hygiene, 1897, XXVIII, 24. See also Table III.

and unfairness of the system of rationing. So there stand two clear issues in relation to the problem of bread: (1) Shall it be rationed, and (2) what percentage flour is the most efficient as human food? In this connection it is worth while to see what action was taken by the British. It must be borne in mind that the problems presented in England were of a different nature than those in Germany. Germany was forced to live upon what she could produce within her own borders plus the small amounts she could get from contiguous nations or occupied territories. England, on the other hand, had to depend to a large extent on the importation of food materials. Hence any form of control in Germany had to extend to the producer, and had a number of evils as well as a host of difficulties. For the state to pre-determine the time and amount which the farmer must deliver involves the risk of serious miscalculations and much irritating interference with the farmer's operations. At the same time, the German system of paying a higher price for grain which was delivered in the later months ended in the grain being held for the advanced price. In either case the government had to deal with a large number of individuals, each one a producer. Just what would have been the effect of allowing bread to move freely without ticket is hard to guess. In England there never was a limit on the sale of bread. To rather encourage its sale the government bought large quantities of breadstuffs and put these on the market at low prices. Price and nutritional value considered, bread is the cheapest food obtainable in normal times, and even when prices are advancing, bread still remains the cheapest food. This fact, and the fact that people will tend to eat more bread as prices rise is shown in the following:

Peace time bread consumption...5¾ lbs. per capita per week.
War time consumption.....10 to 14 lbs. per capita per week.

It will be seen that in pre-war days the workman, then able to fill in his ration with other types of food, ate only 5¾ pounds of bread per week, but when the prices began to rise these other foods, eggs, meat, cheese, etc., increased so rapidly in price that the poor had to depend more and more on bread, because it still remained the cheapest available food.

But all of this Germany was unable to do. The reason is very clear, she did not have enough flour with which to make an unlimited supply of bread, consequently she had to resort to the very system she did. It is in fact more or less waste of time trying to compare the systems in force in the two countries, because the systems followed were the outgrowth of the conditions which existed, and the conditions were the result of a number of causes.

In the past, the science of nutrition, in treating the subject of the body needs of the three classes of foodstuffs, has devoted a great deal of attention to the caloric needs of the body, to the minimum protein requirement, and over this very question of protein has been waged a merry war for years; but it took the war with its subsequent world food shortage to bring into prominence the question of fats. With an individual or a nation living on the average mixed diet there never is a question of protein minimum or maximum, unless it is purely an academic one. In the case of the carbohydrate, it is well known that a certain amount is necessary, sugar being the form in which the body finally deals with this food. If carbohydrates are lacking, then it is possible for the body to split off the oxy-fatty acids which result from the de-aminization of the amino acids of the protein. Data regarding the necessity of fats in the diet are not on record, or are very scanty. Generally, dieticians have assumed that fat and carbohydrate are isodynamically convertible; the fattening of stock from carbohydrate is well known. The isodynamy in the case of carbohydrate is very limited, probably the glycerin radical of the fat molecule offering the basis for carbohydrate synthesis.

That the body needs protein and carbohydrate is known. Is there a similar limit in the case of fats? Inasmuch as the body has the power of converting sugar into fat the physiological needs of the cells for an outside supply of fat appears to be unproven, at least from the viewpoint of nutrition and chemistry. However, there are a number of other considerations to bear in mind. For the past three years the German nation has been on an exceedingly low fat diet, in some cases as little as 30 grams per week per person. The first demand made was for fats. If fats cannot be proven by science to be necessary, at least in the mind of the people fat holds a place of high esteem. There probably is some real reason back of this craving for fats, more than the people themselves know. It is known that the fats are rather slowly digested. Further in the preparation of foods, fats play a large part in the palatability of the dish as it goes to the table. Food coated with hot fat is more palatable and therefore more satisfying, but the fat has another and a more important rôle to play. The digestion of that food is retarded quite considerably, the sense of fullness remains much longer and hunger pangs are not so apt to develop. The Germans had for a long time been eating foods prepared without fats; as a consequence, the methods of preparation were very limited, and lacking the protective fat covering the food was rapidly digested with a consequent sense of hunger rapidly developing. In this case the fats were playing a double rôle, physiological and psychological.

Then, too, there have developed certain diseases both in England and Germany, chief among which is a form of generalized edema, more commonly called war edema. In England this disease followed closely on the development of a fat shortage and cases cleared up rapidly when fat in sufficient quantity was added to the diet. In Germany there was a great deal of the same disease and the same cures were noted. However, the German medical men state that they found it was not necessary to give fats, but that any complete change of diet would clear up the edema.

Living on such a diet as the Germans did for so long must have led in many cases to undue distention of the intestinal tract. The diet was extremely bulky in relation to its heat value. Perhaps the demand for fats comes from this fact as well as those just mentioned. Fat is the most concentrated food we have. It will yield 9.3 calories per gram as compared with protein or carbohydrate, both of which yield only 4.1 calories per gram. The addition of a small amount of fat to

the diet would have added a large increase in caloric value with comparatively little bulk, which would have gone towards relieving the packing of the digestive tract with large amounts of highly indigestible foods.

In the digestive tract the fats are less liable to fermentation than the carbohydrates. The overloading of the intestines with carbohydrates will lead to meteorism, a complaint very common among the Germans, and will lead to more or less chronic forms of intestinal irritation.

In general, then, we have three very good reasons for believing that fats are really quite essential to proper nutrition: (1) They retard digestion and so ward off hunger pangs; (2) they are a highly concentrated form of food; and (3) they are less liable to cause meteorism in the process of digestion."[11]

In summing up the entire situation it will be well to refer to certain memoranda and extracts from reports in order that the entire situation will be seen. On April 8, 1919, the writer prepared the following memorandum on the breakdown of the German food control:

As compared with England, Germany had far the more difficult problem. In England, where most of the food was imported, a barrier at the dock was sufficient; while in Germany, with all imports cut off, it was necessary to control every individual producer. To do this successfully required the full and honest coöperation of every farmer. This the government had during the early days of the war, but later, as food shortages became more acute and prospects of a victory became more distant, the control of the farmer became less and less efficient. The lack of coöperation by the farmer was further augmented by the government's policy of price fixing of foodstuffs, while the price of labor, machinery, animals, and fertilizers continued to soar. In addition, taxes were greatly increased, war loans were being floated, of which the farmer was expected to bear his share. To meet this increased cost of living the farmer resorted to a number of illegal practices, chiefly "Schleich-handel," and as the practice spread the control became weaker and weaker until in the end probably the control covered as little as one-half the total production.

Germany's attempt to ration the nation caused considerable trouble. It caused grave discrepancies in the food supplied. On paper, every man shared alike; in reality, certain people were much better off than others. In the first place, as pointed out by Rubner, it is impossible to arrange a system of rationing food which will meet every individual's needs, assuming an unlimited supply. But, considering the situation in Germany, where the supply was distinctly limited, then a problem in rationing becomes extremely serious. Families with many children were better off than families with no children; hospitals, prisons, and asylums fared badly. Every consideration was given to the war industry worker, while the hard mental worker suffered. No consideration was given to the dietetic habits of various portions of the Empire, no consideration was given to the relative needs of city and country. In the case of the city and country it must be borne in mind that the urban population in Germany was, relatively speaking, a meat-eating population, while the rural population subsisted largely on vegetables and bread. When the one level ration went into effect it resulted in a relative increase in the rural diet, whereby the farmer was able to obtain more meat than in peace times, but he obtained this meat at the expense of the city dweller. And due to the fact that the farmer was the producer of grains, he was able to maintain his former standards of living regarding bread and vegetables. So, as regards city and country, the country had every advantage at the expense of the city, from a dietetic standpoint, while the city had all the advantage from a financial standpoint. "Schleich-handel" was the great adjuster between these conditions. The fact that health conditions, changes for the worse, are more in evidence in the cities lies at least partly in this situation. The situation in Germany has again proven the truth of an old statement regarding the feeding of a nation, that any attempt to control the diet of a large group of people would always be a failure.

The German scienist feels, and not without cause, that had the government heeded the advice offered, the food problem would never have become acute in Germany. The advice given by an expert, on any subject, supposes always, that there is an adequate organization for putting the advice into operation. The fact that the organization, the German Government, was in a process of disintegration must never be lost sight of; and on the other hand, had a more intelligent food program been instituted doubtless the government could have lasted longer. At the very outset the government paved the way for trouble with the farmer by fixing prices for farm produce, and at the same time allowing labor and material to increase. If the law of supply and demand is to operate for one commodity it must operate for all. Nor did the matter of price fixing pass without serious objection in Germany.

In a rather broad way the German Government was advised to reduce stock to a livable minimum, thereby freeing a great deal of grain for human consumption, and at the same time have the population draw a larger percentage of nitrogen requirements from grain and vegetables. The scientist pointed out that 100 pounds of protein from grain passing through a hog or a steer would only deliver 20 to 23 pounds of protein in the form of meat. The scientist proposed to reduce the animals and free the vegetable protein for humans. If this were accomplished there would be less stock to feed with the result that it would not be necessary to grind out meals to a percentage where they would be inefficient as foods, and the discarded bran would be ample for the stock The government, instead of following this rather broad program regarding grain, began by grinding out to 95 per cent, thereby at once reducing the available stock food, which resulted in a great slaughtering, an ample supply of meat for a short time but, in a long run, a meat shortage, undernourished work stock, and poor bread for the people. Instead of making the reduction artificially and gradually, thus allowing for proper care and storage of the meat against future needs, the nation glutted to-day and starved to-morrow. They point out that the stock was reduced, to which the scientist replies that it was not done scientifically.

The seemingly vacillating attitude of the government can be partly explained by the almost hysterical belief that the war was going to be short and decisive. By the time the government officials realized that a long war was ahead the food situation had been so permanently damaged by bad management that it was almost hopeless.

The fact that the hogs in Germany were reduced from 26 millions in 1914 to 8 millions at the present is of little value in proving the efficiency of the food control, when one realizes that this reduction was not done in any thought out attempt to increase food for humans, but was simply the result of a real food shortage. Had the reduction been made immediately, and the meat preserved, Germany would have found herself with more protein in the form of meat and vegetables and more calories. As it was, hogs were fed good human food far past the point of efficiency, and then slaughtered when there was nothing more for them to eat.

The scientists advised a rather flexible type of rationing, realizing full well the difficulties which a hard and fast régime presented from a dietetic standpoint. Opposed to this was the government policy which proposed an equal distribution with no regard for the justice of the same. To determine a just distribution based on

[11] Starling: The Significance of Fats in the Diet. Brit. Med. Jour., August 3, 1918.

sound dietetic principles was an almost impossible task, so the government took the easier if less efficient method. Rubner in 1917 advised a return to the normal method of allowing each person to determine his own ration. But the practical problems connected with Rubner's proposal were too complicated.

Many instances of clash of the scientific advisors and government administrators are obtainable. In each case the scientist prophesied unerringly the outcome unless his advice were taken and followed; on the other hand, the practical difficulties of meeting the advice offered were nearly insurmountable.

On February 15, 1919, the writer made the following report to the Supreme Economic Council in Paris in connection with the food situation and its development. This report, together with the charts, will show something of the events which led up to the final days of the war.

The German farmer bore the brunt of the war. His labor was taken for the army and the associated war industries, his animals were taken for military purposes, the prices he could receive for the staples were fixed at a not too high level, he was cut off from an adequate supply of fertilizer, he was given the task of feeding a greatly enlarged non-producing population; all this the farmer was expected to do and in addition he must, successfully to accomplish his task, overcome the annual German shortage of food, the 10 per cent which Germany in peace times had always found it necessary to import. At the very outset the food producers were under a heavy handicap. (See Chart I.)

Germany faced one of two alternatives, either to reduce the national food consumption or to increase the national production. Eventually she did the latter, though not until she had tried every possible way to get more food. There is no doubt but that the 10 per cent imported food was a luxus consumption, the average German was overweight and overfed and would have lived better and longer had he eaten less; but the German was a "good feeder," so it is not surprising to find that his first efforts looking to a solution of the food problem should be along the line of increased production, leaving the matter of decreased consumption to take care of itself, as it eventually has.

With this end in view the farmer was urged to increase his acreage, to make every effort to increase the yield, appeals being made to him along the lines of patriotism and duty. These did very well during the first enthusiastic days of the war. Eventually the government placed money premiums on increased plantings, 40 marks per hectare in the case of potatoes, and in addition offered large prizes to the Kreis showing the greatest relative increase. These efforts had their effects, naturally, and the acreage was increased, though, as a rule, the total yield was decreased, and every increase in acreage was made at the expense of some other necessary food product.

The course of events which took place rather followed the following lines: The British blockade, by cutting off importations to Germany, made an increased production imperative. To accomplish this end there resulted a general increased acreage, but owing to the fact that there was a labor shortage (men had gone to the army and war industries), an animal shortage (horses were taken for military use), and a fertilizer shortage (no guano could be imported and the lack of animals cut down the supply of manure), this increased acreage finally resulted in an actual decreased production, not only of food for humans, but of food for the stock as well. To overcome the shortage of grains and supply more bread the flour for baking was milled to 94 per cent; these high percentage flours cut off a great amount of bran which meant less stock food. The shortage of stock food led to undernourishment of the cattle, which was felt particularly in the milk and butter production as well as in the lowered meat supply. The latter was not so seriously felt, due to the fact that when there was a threatened fodder shortage the stock was killed to save it. In this way the German hog supply was reduced from 26 millions in 1914 to less than 8 millions at present. Eventually this excessive slaughtering was felt in a greatly reduced meat supply, not only of pork, but of beef as well.

Thus there was set up in Germany a vicious circle of events, and any measures taken to relieve the pinch in one direction always caused an increased pressure in some other. It was a case of trying to overcome the 10 per cent handicap under which Germany was working, and due to the effectiveness of the British blockade this was impossible. Follow to its ultimate end any one of the problems which Germany faced in trying to solve her nutritional puzzle during the war and the trail will in the end lead to the blockade. All the juggling of food materials in Germany could not increase the total supply in the least, and as this supply annually became less and less, the pinch of hunger became more and more serious.

To show just how this correlation of activities worked out and to show statistically how pressure in one quarter caused serious results in another, three charts, V, VI, and VII, have been prepared. V shows graphically what was accomplished in a representative Kreis in the way of increased production. (Kreis Mayen is one of the most productive districts in Germany and figures from Mayen may be taken as a fair index to all agricultural Germany.) A study of this graph will show that, the importance of wheat and potatoes being realized, the total acreage planted to these foods was increased at the expense of barley and rye. In every case there is a decrease in the per hectare production due to the reasons already outlined. Only in the case of wheat is the total production increased, rye and barley with decreased acreage and decreased unit production show a decided total loss, while in the case of potatoes the increased acreage was not enough to overcome the loss per unit with a resulting decrease in total production.

The results of the decreased production of grains and potatoes are shown in Charts VI and VII. Chart VI details what happened to the cattle and the dairy products. The actual loss in the number of cattle was not as great as might have been expected, a loss of 20.5 per cent. This loss was greatest in the case of young stock, the milk cattle suffered a loss of 8.8 per cent, while the oxen, because of their great value as substitutes for horses, show a loss of only 2.8 per cent. From this it will be seen that the younger stock went, for the most part, to make up the meat supply of the country, this fact, together with the undernourished condition, accounting for the 30.5 per cent loss of dressed weight of carcasses. To-day the herds of Germany are for the most part composed of the older cattle. In the case of dairy products the undernourishment of the milch cows is strikingly shown by the large reduction in milk which amounts to 55 per cent. Considering that there has been only an 8 per cent reduction in the number of milch cows, this figure is enormous. Not only was the milk actually reduced in quantity, but it has suffered a decided lowering in quality, shown by the fact that in 1914 100 liters would produce 7.1 pounds of butter, while in 1918 100 liters would produce 6.2 pounds, a decrease of 12.7 per cent. A milch cow then, has lost 60 per cent of her 1914 efficiency. From this it can be seen that the crop shortages quite decidedly affected the stock situation, causing a reduction in the meat supply and a lowering in both the quantity and quality of the milk supply.

The final effects of the facts brought out in Charts V and VI are shown in Chart VII. At this point the population or the consumer is involved. There is a great reduction in the number of calories of food available; in 1913 the German consumed about 3000 C.[13] daily which in 1918 had dropped to between 1200 and 1400 daily, depending on the locality. The daily milk supply of the city of Coblenz fell from 22,000 liters in 1913 to 3000 liters in January, 1919. The fat supply in the same place was reduced from 300

[13] This figure has been arbitrarily set and is open to that criticism.

I

Average Daily Consumption of Foodstuffs
Germany
Average for 1912 & 1913

Foodstuffs	Consumption				Contribution from Abroad			
	Actual Nutriment							
	Protein	Fat	Carbo-hydrate	Calories	Protein	Fat	Carbo-hydrate	Calories
	In Grams				In Grams			
	I Vegetable Foodstuffs							
Vegetable Foods	46.2	5.0	411.0	1,916	6.6	0.4	40.4	196
Green Vegetables	3.1	0.5	15.5	80	0.1	0.0	0.6	3
Fruit	0.9	1.4	16.9	87	0.2	0.4	5.4	26
Sugar & Honey	0.0	–	48.8	195	0.0	–	24.0	96
Vegetable Fats	–	7.6	–	71	–	6.5	–	61
Cocoa	0.1	1.0	0.4	11	0.1	1.0	0.4	11
Alcoholic Liquors	1.1	–	14.1	173[1]	0.2	–	1.9	20[2]
Total	51.4	15.5	506.7	2,533	7.2	8.3	24.7	221
	II Animal Foodstuffs							
Meat & Fats	17.7	55.0	0.1	585	3.5	13.0	0.0	131
Fish	2.2	1.2	0.1	12	1.4	0.3	0.1	14
Dairy Produce	19.7	32.5	23.5	478	12.6	16.1	18.8	278
Eggs	1.9	1.8	0.1	26	0.8	0.7	0.0	11
Total	41.5	90.5	23.8	1,109	18.5	36.7	18.9	434
	III Total Foodstuffs							
	92.9	106.0	530.5	3,642	25.7	45.0	43.6	715

(1) Including 112 calories of alcohol
(2) Including 11 calories of alcohol

II

Per Capita Total and Weekly Averages of All Foods Issued in Bonn, Germany, by Six Month Periods from July 1, 1916 to January 1, 1919

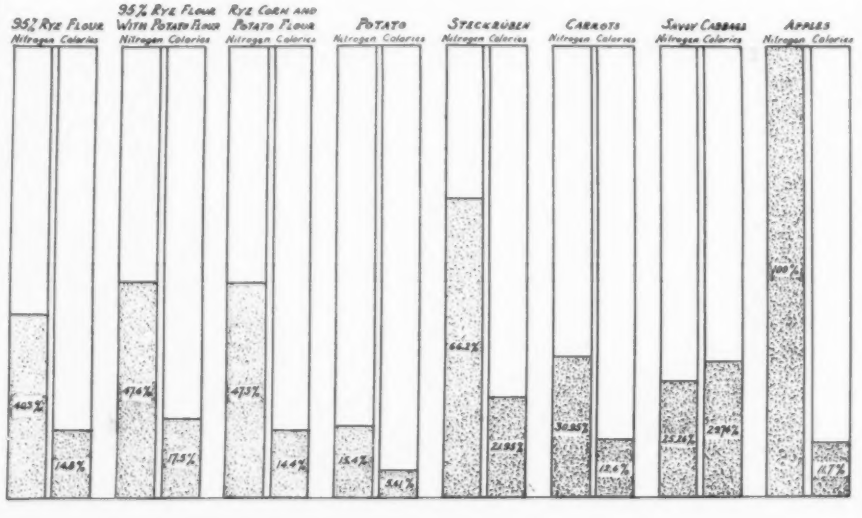
All Figures Are In Grams	1 July 1916 to 1 January 1917	1 January 1917 to 1 July 1917	1 July 1917 to 1 January 1918	1 January 1918 to 1 July 1918	1 July 1918 to 1 January 1919
Meat	3338	5,188	4490	3910	2525
Sausage	4508	2,070	1340	720	685
Bacon	425	1,400	200	100	–
Total	8271	8658	6030	4730	3210
Average per week	318.06	332.97	231.93	181.92	123.47
Fish	4320	135	–	–	203
Eggs	11 Eggs	11 Eggs	8 Eggs	7 Eggs	8 Eggs
Cheese	62.5	50	50	125	337
Butter	860	630	680	760	950
Lard	305	30	150	100	80
Margarine	535	735	505	710	300
Oil	–	105	120	70	–
Total	1700	1500	1455	1640	1830
Average per week	65.64	57.69	55.95	63.10	51.16
Bread	50,880	46,500	47500	47,750	43625
Average per week	1957	1788.96	1826.92	1836.54	1908.65
Cereals	9625	8050	5500	6150	5550
Average per week	370.20	309.60	211.53	236.54	213.46
Rice, Sago	–	125 (Rice)	250 (Sago)	–	–
Legumes	750	750	100	–	350
Sugar	4500	4150	4900-7400	5300	7650
Average per week	173.08	160	188.5-284.62	203.85	294.23
Marmelade	750	2,375	3500-6000	5875	2625
Potatoes	95,500	52,500	65250	111,500	98,500
Average per week	3673.08	2019.23	3278.85	4288.46	3788.46
Potato Flour	–	–	425	425	250
Turnips	4000	48000	15000	51000	–
Vegetables	–	5375	2300	9625	750

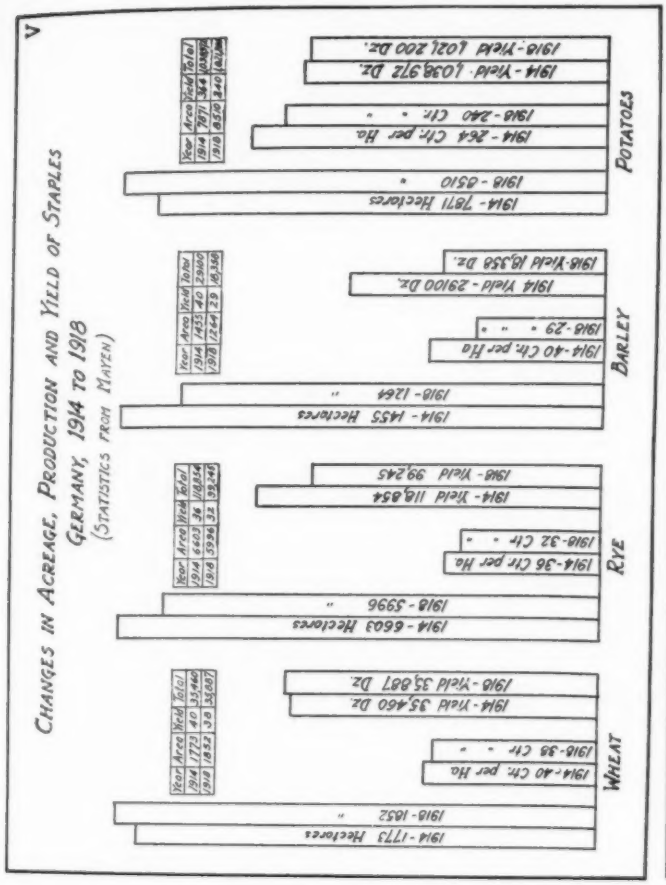
Analysis by Half Year Periods
Daily Allowances

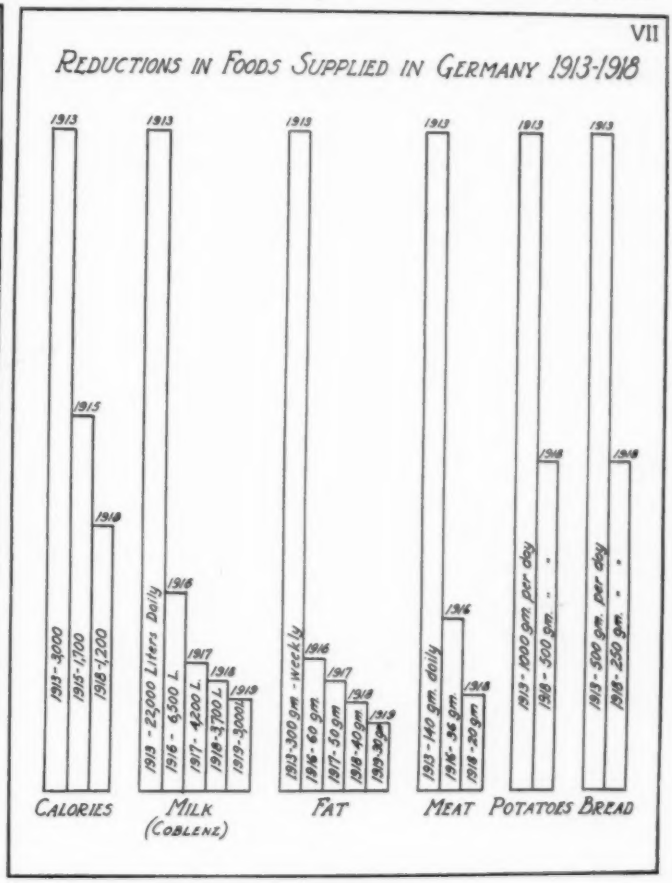
Protein	42.59	39.62	36.67	39.85	34.41
Fat	20.42	19.44	12.85	13.06	10.49
Carbonydrate	298.25	267.61	290.25	326.22	298.67
Calories	1587.43	1440.43	1460.00	1619.81	1463.19

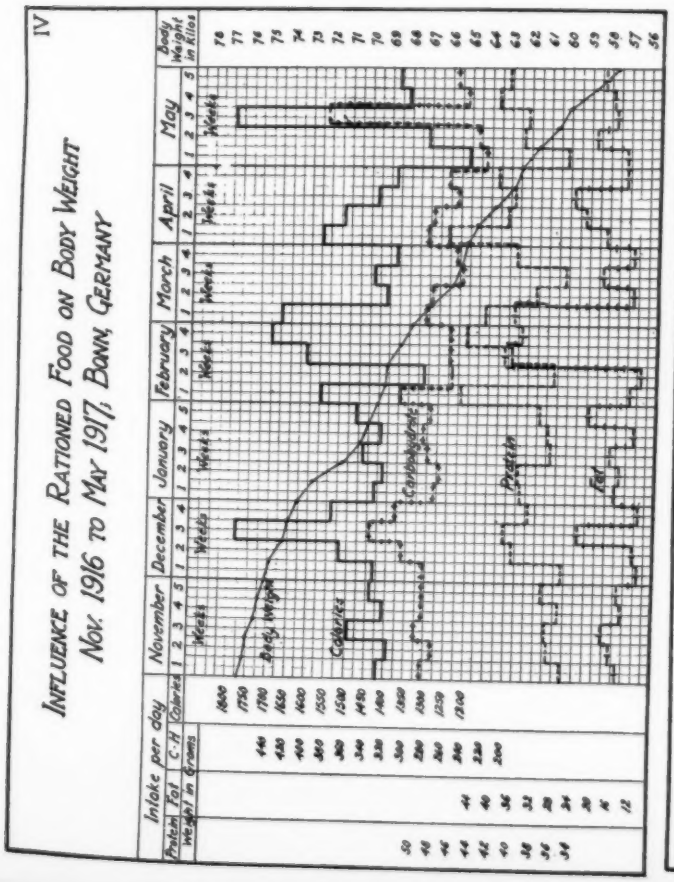
III

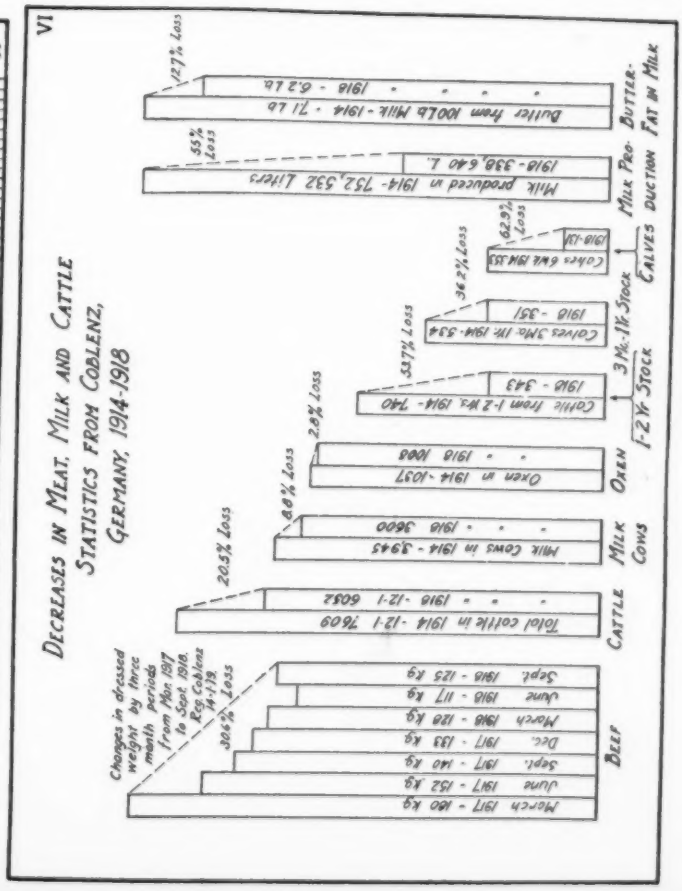
Digestibility of Foods
Total Column Represents 100 Units
Portion Shaded Red Represents Amount Lost in Digestion
Portion Unshaded Represents Amount Utilized by Body




V
CHANGES IN ACREAGE, PRODUCTION AND YIELD OF STAPLES
GERMANY, 1914 TO 1918
(STATISTICS FROM MAYEN)
POTATOES
BARLEY
RYE
WHEAT
1914 - 1773 Hectares
1918 - 1652 "
1914 - 40 Ctr. per Ha.
1918 - 38 Ctr. " "
1914 - Yield 35,460 Dz.
1918 - Yield 33,887 Dz.
1914 - 6603 Hectares
1918 - 5996 "
1914 - 36 Ctr per Ha.
1918 - 32 Ctr. " "
1914 - Yield 118,854
1918 - Yield 99,245
1914 - 1455 Hectares
1918 - 1264 "
1914 - 40 Ctr. per Ha.
1918 - 29 " " "
1914 Yield - 29100 Dz.
1918 Yield 18,358 Dz.
1914 - 7871 Hectares
1918 - 8510 "
1914 - 264 Ctr. per Ha.
1918 - 240 Ctr. " "
1914 - Yield 6,038,972 Dz.
1918 - Yield 4,021,200 Dz.


VII
REDUCTIONS IN FOODS SUPPLIED IN GERMANY 1913-1918
CALORIES
MILK (COBLENZ)
FAT
MEAT
POTATOES
BREAD
1913 - 3000
1915 - 1,700
1918 - 1,200
1913 - 25000 Liters Daily
1916 - 6,500 L.
1917 - 4200 L.
1918 - 3700 L.
1919 - 3000 L.
1913 - 300 gm - weekly
1916 - 60 gm
1917 - 50 gm
1918 - 40 gm
1919 - 30 gm
1913 - 140 gm. daily
1916 - 34 gm.
1918 - 20 gm.
1913 - 1000 gm. per day
1918 - 500 gm. " "
1913 - 500 gm. per day
1918 - 250 gm. " "


IV
INFLUENCE OF THE RATIONED FOOD ON BODY WEIGHT
NOV. 1916 TO MAY 1917, BONN, GERMANY
Intake per day
Protein
Fat
C.H.
Calories
November
December
January
February
March
April
May
Body Weight in Kilos
Body Weight
Calories
Carbohydrate
Protein
Fat


VI
DECREASES IN MEAT, MILK AND CATTLE
STATISTICS FROM COBLENZ,
GERMANY, 1914-1918
Changes in dressed weight by three month periods from Nov 1917 to Sept 1918. Reg Coblenz 14-17.
BEEF
CATTLE
MILK COWS
OXEN
1-2 YR. STOCK
3 MO.-1 YR. STOCK
CALVES
MILK PRODUCTION
BUTTER-FAT IN MILK
Sept. 1918 - 125 kg
June 1918 - 117 kg
March 1918 - 128 kg
Dec. 1917 - 133 kg
Sept. 1917 - 140 kg
June 1917 - 152 kg
March 1917 - 160 kg
Total cattle in 1914 - 12-1 7609
" " 1918 - 12-1 6052
Milk cows in 1914 - 3945
" " 1918 3600
Oxen in 1914 - 1037
" " 1918 1008
Cattle from 1-2 Yr. 1914 - 740
1918 - 343
Calves 3 Mo. 1Yr. 1914 - 334
1918 - 351
Calves 6 Wk. 1914 - 35
1918 - 13
Milk produced in 1914 - 752,532 Liters
1918 - 338,640 L.
Butter from 100 Lb. Milk - 1914 - 7.1 Lb.
" " " 1918 - 6.2 Lb.
20.5% Loss
8.6% Loss
2.9% Loss
53.7% Loss
36.2% Loss
62.3% Loss
55% Loss
12.7% Loss

grams per capita per week in 1913 to 30 grams per capita per week in 1919. Meat, which had been furnished at the rate of 140 grams per person per day in peace times, was reduced to the low figure of 20 grams in 1919. Bread and potatoes both suffered a 50 per cent reduction, and in the case of bread the quality fell as much.

By following through the rather involved and ramified activities of the Germans in their attempts to overcome the 10 per cent handicap in food supplies and to feed the vast number of non-producers connected with the war machine, it becomes increasingly clear that the greatest barrier betwen the German people and an adequate food supply was the British fleet.

The failure to increase production is the main part of the story, though by no means all of it, the problems of control and distribution being also of great importance. Dr. Neumann, of the University of Bonn, after a careful study of the whole question states that in his opinion if there had been complete control of food supplies in Germany the population would have been one-third better fed. During the early days of the war the great patriotism of the people together with the popularity of the war made control rather easy. As the war wore on and food became scarcer and scarcer the farmer gave up his excess less and less willingly, especially when he found that he could sell illegally at very high prices. There were many ways to evade the law, and no doubt all were used. Long after it had been officially announced that certain foods were off the market or the supply exhausted one could still obtain them provided adequate payment was made. This fact made it possible for the well-to-do to have ample supplies most of the time. Further studies into this matter of control made it quite evident that the government did not control the food as far as would appear on first examination. Towards the end of the war, when there was nothing but defeat staring Germany in the face, the Reichs government became very weak, and the farmer who had borne the burden of the fight grew less and less tractable, giving smaller and smaller amounts of food.

For the first time in history the world at large faces a universal food shortage. Heretofore scarcity of food has been only local, the famines of India and Ireland being well-known examples, and in these cases it was always possible for other countries to get food to the lands of shortage. To-day there seems reason to believe that in the whole world there is not all the food which could be consumed by all the people. The war, with its numberless ramifications, especially its connection with the food question, has driven into the public mind the fact that after all there is something to be learned about mass feeding, or public rationing. There seems little doubt that a new type of work is going to be developed, food control. It is well to make clear that there are real differences between food control and rationing. Food control can be a success, mass rationing will always be a failure. By food control, as the term is now used, is meant a control of those activities which tend to dissipate the energy contained in food and a more complete conservation of the same. Broadly speaking, any activity which tends to raise the price of any article of food above its normal level tends to destroy the usefulness of the food and in that way works against the greatest public good. Under this type of activity we can class such things as useless transportation, too many middlemen, or withholding foods from the market in order to maintain a price. Inasmuch as such procedures tend to keep the food out of the hands of the consumer they work against fullest conservation of national resources. Along the lines of positive control there is a great deal of work to be done on the stock question, the relationship which must exist between the number of people and the amount of livestock to be maintained. This problem alone played a quite important part in the German food question all during the war. Then the control of live stock is intimately wrapped up with the question of the milling of flours, the choice of grains to be milled, the percentage to which they shall be made of the millings.

All these are new problems, problems which must be studied and worked over for years to come. It will need the combined work of the nutritional expert, the economist, the railroad man, the politician, the psychologist, and the housewife to ever reach any satisfactory working basis; more than that, it will have to meet with the approval of the people. But such steps must in no wise tend to hinder the people from choosing and buying what they wish when they wish it. The average person is by far the best judge of his own nutritional needs; the proof lies in the fact that the race continues to live and live a normal, healthy life. Any person or group of persons which attempts to set down a hard and fast ration for the masses will soon find a sick, discontented nation of people.

From a study of the feeding problem it would appear that the real question of calculating scientifically, according to the best findings of physiology and nutrition, the exact needs of the average man is rather simple, and can be done with the accuracy of any mathematical problem. But no mere scientist can possibly take into account in such calculations the personal likes and dislikes of each individual, the racial dietetic habits, the sectional dietetic habits, the climatic dietetic demands, the thousand and one daily variations in the psychical make-up of each individual, and to make a ration satisfactory all these things must be considered. To ration a race we must assume the infinite amount of work which each person is capable of doing much more efficiently and satisfactorily for himself. Germany tried it and failed, England contented herself with control and succeeded.

We can draw some very important conclusions from the experiences of England and Germany in relation to this problem of mass feeding under conditions of famine, blockade, or siege.

1. Food control, *i. e.*, food conservation must be practiced by every person.

2. Live stock must be reduced to a level compatible with the grain supply.

3. The people must subsist on a larger percentage of vegetable products, increasing the amount of land used for such crops as rapidly as such land is freed from the support of live stock.

4. Bread will form the staple of diet, so the milling of the flour must be carried out in the most efficient manner, taking into consideration the actual nutriment to be given to humans and to stock.

5. Rationing must be limited to those articles which are luxuries; necessities, *i. e.*, bread, meat, potatoes, etc., must be permitted to circulate freely. (In case of actual siege or practically closed blockade it may become necessary to enforce stringent rationing.)

6. The psychological aspects must never be overlooked.

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PATHOLOGICAL CHANGES IN THE GASTEROPOD LIVER PRODUCED BY FLUKE INFECTION

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Because of the significant contributions that have been made to normal metabolism by a study of pathological conditions, the writer has been prompted to make a study of the liver of certain gasteropod species commonly infected with larval flukes, with the view of discovering the normal metabolic processes of the host, the changes occasioned by the parasitism, and the application of these data to comparative pathology.

The data on histological pathology of animals induced by helminth parasitization are indeed meager. Text-books on pathology make little or no mention of the gross lesions and symptomatology and give nothing at all on the more detailed pathological pictures of such lesions, because so little first-hand investigation of the subject has been made. This is especially true of diseases of the hepatic organ caused by helminth parasites, the significance of which is little understood. Since the properties of secretion, absorption and excretion are common to the hepatic gland of the snail and the vertebrate, a study of the infected liver of the snail justifies itself as one of comparative pathology which is readily interpreted in terms of vertebrate pathology.

The material on which this study is based consists of many thousand sections of water pulmonates from all over the United States, from South America (*Planorbis guadelupensis*), and from South Africa (*Physopsis africana*). In addition, living *Planorbis trivolvis* and *Physa sp.* have been used in microchemical tests and analyses. Many of the specimens from which sections have been prepared have been fixed in corrosive-acetic or corrosive-nitric mixtures, but some have been killed in corrosive sublimate alone and others, as a check, in formol-alcohol. Sections have been uniformly cut 8 μ thick and stained in Delafield's hematoxylin with eosin counterstain. To some of these sections Best's potassium-ammonium-carmin stain has been added to check the iodin tests for glycogen.

THE NORMAL GASTEROPOD LIVER

The gross structure of the gasteropod liver was worked out by Swammerdam (1737), who described and correctly figured the main features of the organ. Later workers have not materially altered this classical description. No attempts at a detailed histological study of the mollusk liver were made

until the middle of the nineteenth century, when Leydig (1850) published his monograph on *Paludina vivipara*. Since that time numerous students of histology and physiology have published their researches, which, on the whole, are decidedly conflicting and contradictory.

The liver of the gasteropod consists of racemose tubules which arise from two embryological outpocketings from the mid-intestine. The tubules are lined with glandular epithelium and are bound together by a meshwork of interstitial cells in which are found branches of the hepatic artery, blood lacunæ, bile-ducts and numerous nerve endings. The whole gland is enclosed in an epithelial sac, the tunica propria. Although the cells of the tubules and their respective functions have been the subject of intensive analysis, little attention has been paid to the intimate structure of the intertubular portions of the organ and their relations to the tubules.

Some investigators have found as many as four kinds of epithelial cells opening into the lumen of the tubule, but most workers have described three. Barfurth (1883) has designated these as ferment cells, liver cells and lime cells. The ferment cells of Barfurth are referred to by Biedermann and Moritz (1899) as secretion cells and the liver cells as resorption cells. Frenzel (1884) has attacked Barfurth's theory that the lime cells contain tri-calcium phosphate granules. Although Barfurth's proof is certainly open to question, Frenzel's critique is unconvincing.

The data justify the belief that the epithelial cells of the tubule act as a digestive organ in the secretion of diastatic and peptic ferments, that they are the mediary absorptive organ for glycogen, fats and peptones, and that they function in the excretion of certain types of wastes.

Contrary to the view of the European workers, who have recognized at least three types of cells in the epithelium of the tubule, the writer is obliged to conclude that there are, from a purely cytological standpoint, only two kinds, the rhomboidal or tetragonal cells with large spherical nuclei (the lime cells of Barfurth), and the more common kind, irregularly palisade in character, with small oval nuclei, comprising both the ferment and the liver cells of Barfurth.

The "Lime Cell."—Barfurth (1883: 500) states that the water snails differ from the land species in that the "lime cells" are entirely lacking in the former and are always present in the latter. Despite this statement the writer has consistently found the type of cell in which Barfurth claims that tri-calcium phosphate crystals are stored up, in all normal liver tissues of *Planorbis trivolvis, P. guadelupensis, Physa gyrina, Physa sp., Lymnæa proxima, Goniobasis carinifera,* and *Physopsis africana* (see Fig. 1). The make-up of this cell is not essentially different from the "lime cell" of *Helix pomatia* figured by Schneider (1902: 570, Fig. 477). In normal uninfected tissues it is roughly rhomboidal in shape and is situated basally, seldom opening into the lumen of the tubule. The nucleus is usually spheroidal with many distinct chromidial granules and a large karyosome. At times the outline of the nucleus becomes irregular, suggesting a polymorphonuclear condition. The cytoplasm is decidedly reticular, with large opalescent spheroidal or ovoidal granules entirely filling the interstices between the threads of the reticulum. These are the granules which Barfurth has claimed for land pulmonates to be the tri-calcium phosphate deposits. Evidence in support of Barfurth's thesis is decidedly lacking. Provided the investigator was able to get a test for both phosphorus and calcium and to isolate tri-calcium phosphate from the tissues, even then the circumstantial evidence constitutes no proof that these elements exist as this salt in the so-called "lime cells." Moreover, the fact that these cells have been found in every normal tissue of water pulmonates examined by the writer, together with Barfurth's statement that tri-calcium phosphate does not occur in water pulmonates, constitutes strong evidence against Barfurth's theory. Furthermore, these deposits in the "lime cells" are not crystalline, as demonstrated by the petrographic microscope, and, while tri-calcium phosphate may exist as a colloid, the behavior of these granules in pathological cells favors the view that they are not lime cells. It is quite possible, as Frenzel suggested (1884: 326), that they may be phosphoproteins, but their reactions to dyes suggests a relationship to basic proteins. It is certain that these cells serve a very specialized function in storing up food masses.

Ferment and Liver Cells.—These cells have been described as distinct types by certain authors. The ferment cells are believed to be unique in the secretion of enzymes which aid in digestion, whereas the liver cells are those in which storage of reserve food takes place. In addition, excretory functions have been assigned to each of these types. Cytologically the writer is able to recognize only one type; physiologically he is able to find many kinds of types which grade into each other almost imperceptibly. The single type of cell, which appears to contain within itself the properties of digestion, absorption and secretion, is palisade in structure, with an oval nucleus in the basal third and an elongate distal end which extends to the opening of the tubule (Fig. 1). In the region of the liver tubule the ends of these cells are protected by a pseudo-cuticula which stains as a mucoid. The changes which have been described and which have given rise to the differentiation of ferment and liver cells are those induced by: (1) The preparation and secretion of digestive enzymes; (2) the taking in by absorption of carbohydrate (stored as glycogen), fats and proteins; and (3) by the elimination of wastes of an excretory nature. In view of the fact that this type of cell is comparable in part to the vertebrate liver cell, the term *liver cell* should be preserved and used for both liver and ferment cells of authors.

During a period of feeding the liver cells are rich in glycogen and fat inclusions and may also test for proteins foreign to the protoplasm. During hibernation and enforced starvation these food products for the most part disappear and frequently large vacuoles appear in the cytoplasm. Likewise, during hibernation and at other times when the respiration is low, excretory granules accumulate in the vacuoles. Under conditions of optimal metabolism these granules are found singly or at most in small aggregates.

MACROSCOPIC APPEARANCE OF INFECTED SNAILS

In order to examine a snail for parasites the apex of the spire is carefully removed, exposing the tip of the liver. The entire animal is then removed through the artificial opening. Normal liver tissue has a characteristic brownish-yellow appearance, differing considerably in the exact shade at various times according to the kind of food consumed. In Planorbis the tunica propria is fairly well separated from the liver tissues proper. In some other species it is thin and closely applied to the tubules, so that their outline is readily made out from gross inspection. But infected material, especially if the infection is heavy, may usually be detected by the removal of the shell. The liver portion is puffed out and, if the infection is severe and of long duration, frequently tubercular in appearance. In Planorbis the red of the blood has been lost and, in its place, in the case of infection with several kinds of flukes, a reddish-brown or yellowish-brown pigment is found in the tissues of the parasite. The pigment suggests a process similar to the production of bile pigment from the hemoglobin of the vertebrate red blood corpuscles. In many species of invading parasites (monostomes, amphistomes, eye-spotted distomes) the melanin pigment of the parasite shows through the tunica propria of the host. In other cases the definite outlines of the parasite spore-sacs are seen through the epithelium. Usually under these conditions the host tissue looks a sickly yellow. A very delicate prick with the needle produces a lesion in the tissues through which in heavy infections the parasites pour forth in large numbers.

METHOD AND ROUTE OF INFECTION

The animal at the time of immigrating into the mollusk (the miracidium stage) and at the time of emigrating (the cercaria stage) has spines for mechanically piercing the host tissues and a secretion is poured forth that digests away the cells of the snail that lie in the path of the parasite. These organs are substantially aided by the muscular equipment of the fluke, and especially in the case of the cercaria by the acetabular suctorial apparatus.

Authors state that the miracidium wanders into the host and changes into a sporocyst. Leuckart (1901: 263-265) has seen the miracidia of *Fasciola hepatica* swarm around *Lymnæa trunculatas* soon after the two species had been placed in the same aquarium. While some clung to the muscle of the foot and others to the mantle fold, still others worked their way up the breathing pore into the lung. The writer's findings are thoroughly in accord with Leuckart's further suggestion that the invaders follow the course of the blood and finally lodge in the liver tissues. Evidence that the invasion is through the blood and lymph channels and not through the lumina of the liver tubules is twofold: (1) The parasites are always found in the connective tissues and the interstices between tubules, while the portions of the epithelial cells bordering on the lumina are always intact except in the most necrotic tissues. (2) The food which the parthenita takes in first of all is from the lymph. This accounts for the pigment so frequently seen in the body of the sporocyst and the gut of the redia. This method of invasion is different from that of the liver fluke as it enters the definitive host, in which case the actual transfer to the digestive tract of the sheep is passive and the passage is by way of the bile-duct. But it does conform to the general method and route of the blood flukes, which do not encyst but bore their way through the skin into the lymph sinuses and finally secure a circulation in the blood.

PATHOLOGY OF INFECTED LIVER CELLS

As soon as the miracidium secures a lodgment in the tissues of the mollusk an irritation is set up, as is evidenced by the nervous movement of the mollusk. Certain larvæ which bore into the resistant muscles of the foot soon become tightly lodged there and never reach a breeding place. Those which get into the blood stream are at most only slightly injurious to the host until they reach the liver sinuses. Lodgment here places the flukes in the direct course of food distribution and, with the metamorphosis into the sporocyst, growth begins. Germ balls arising parthenogenetically increase the bulk (Fig. 2). When a second parthenitic generation is producing cercariæ the bulk of the parasites has been increased enormously over the original microscopic size. Indeed, a heavily infected snail may contain a far greater amount of parasites than its own net size or weight. Aside from the energy required to carry it about, the pressure on the tubules is such that the lumina are almost completely closed and consequently the food supply is lessened. When this means of relieving pressure is used to its utmost the tunica is tightly stretched. Under such circumstances the least prick of a needle causes a rupture, through which lymph and parasites are squirted out. Such a direct mechanical burden is distinctly dangerous to the infected host, but this burden is augmented by the food ration demanded from the host in increasing amounts as the parasite develops.

Rapid increase in number and size of the individuals of the brood developing in the parthenitæ depends primarily on the available food. This must be furnished by the host. The location of the parasite in the blood sinuses of the liver or, as in the case of some fluke parasites, in the gills, intercepts the food supply of the host in transit to the organs. Microchemical evidence supports the view that most of these foodstuffs are requisitioned by the very young germ balls, in which a large amount of glycogen, fats and undigested proteins are found. In case of the close apposition of the fluke to the epithelium of the host (Fig. 3), these materials pass through from host to parasite without ever reaching the blood.

This heavy drain on the food supply of the host is easily demonstrated. Under normal feeding conditions snails which are not infected give a heavy test for glycogen, fats and proteins throughout all of the cells of the epithelium of the tubules. Most of the glycogen and fats are in the liver cells, while the protein storage cells give a heavy test for protein materials. On the other hand, heavily infected tissues give at most only a very scanty test for foodstuffs in the epithelium, a fairly heavy test in the intertubular sinuses, and a decidedly heavy test in the parasites. That the parasite makes direct use

of these foods is thus proved, but whether the several enzymes which are required for absorption and assimilation are localized in certain cells or are the general property of all the cells remains to be actually demonstrated.

When the supply of available foods has been exhausted the parasite has usually reached a state of development where motile cercariæ are present. These, by their continued jerking back and forth free themselves from the parthenita. In practically all species glands are present which help to digest the cells of the host. In this they are usually aided by powerful acetabula by which attachment to a particular group of cells is effected and the digestive processes thus accelerated. First the connective tissue cells of the sinuses are broken down and the cytoplasm utilized. It appears, however, that the nuclei are more difficult to digest. Then the epithelial cells of the tubules are subjected to the cytolytic action. By this time, however, other more truly pathological conditions have developed, due to the excretory wastes of the parasites which have accumulated in the host tissues.

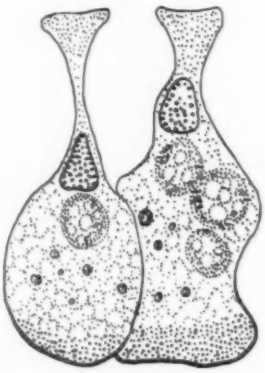
Excretions.—The normal excretory process in the liver cells is effected directly by the formation of vacuoles within the cytoplasm of the epithelial cells and their extrusion into the lumina of the tubules. At times small concretions of protein katabolism are found within these vacuoles. The content of the vacuoles, whether fluid or solid, is eosinophilic, and the cytoplasm immediately around these vacuoles frequently tests acid. Thus it is seen that the route of excretion in the immediate vicinity of the liver cells is just the reverse of that of digested food.

The effect of the parasite on the excretory process of the mollusk is twofold. The host is required to dispose of the parasite's excretory wastes and by the various pathological processes initiated within the host tissues increasing amounts of its own nitrogen and other decomposition products must be disposed of. Part of the wastes from the parasite goes into solution in the lymph and is passed on to the kidneys, but a large group of developing flukes in a blood sinus soon come to form an obstruction which produces a stasis sufficient to cause an accumulation of waste products at that particular focus. The amount of this wastage from the parasite is very great. In hibernating conditions (encysted) the fluke may accumulate an amount of excretory wastes several times the size of its own body.

The greatest harm results, however, from the cytolytic and cytotoxic effect of these parasite wastes on the host. While certain harmful effects obtain from the mechanical burden of the fluke and from its consumption of food intended for the tissues of the snail, the pathological picture is much more intensified by the direct effect of the secretions and excretions of the parasite. The normal reaction of the epithelial tissues of the liver is alkaline, although the presence of excretory materials may cause an acid reaction in the immediate vicinity of such wastes. But the parasite, when once thoroughly established in the blood sinuses, tends to produce an acid reaction throughout the entire tissue. It is important to note, however, that the snail is able to a marked degree to counteract this acidity by rapidly filtering the wastes through the epithelium into the lumen. This tends to preserve an alkaline condition at the base of the cells nearest the point of attack of the parasite, while the free ends of the cells are usually quite acid.

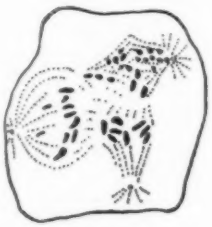
The first reaction of either type of epithelial cell to the abnormal products caused by the parasite is to work these out of the cytoplasm into vacuoles which are forced toward the free end of the cell and extruded into the lumen (Figs. 2, 5, 6, 7). But the ability to make this adjustment is limited, and failing to eliminate the poisons forced into the system, the host cells are subject to characteristic lytic changes. Previous to this time the glycogen and fats which had been absorbed by the liver cells have passed through into the blood sinuses and thence into the developing flukes. But the parasites seem to be unable to utilize the protein particles stored up in the "lime" cells and these begin to degenerate. They accumulate in dense agglomerates between the nucleus and the free end of the cell (Fig. 5, Text Fig. 1), taking on a dense basophilic stain. Their reaction is suggestive of a complex mucoid. Little by little these dense agglomerates become worn away and finally dispersed throughout the cell. Closely associated with this type of katabolism is the breaking down and extru-

TEXT FIG. 1.



TEXT FIG. 3.

TEXT FIG. 2.



TEXT FIG. 4.

TEXT FIG. 1.—"Lime" cell of *Pl. trivolvis* with large excretory vacuoles and concretions resulting from infection with *C. convoluta*. (× 1080.)

TEXT FIG. 2.—Polymorphonuclear "lime" cell of *Pl. trivolvis* extruding chromidia through cell wall into lumen of tubule; infection as in Text Fig. 1. (× 1080.)

TEXT FIG. 3.—Liver cells of *Pl. trivolvis*, showing large number of excretory vacuoles and granules due to infection with *C. acanthostoma*. (× 1462.)

TEXT FIG. 4.—"Lime" cells of liver of *Planorbis trivolvis*, showing multipolar spindle due to tissue infection with *Cercaria convoluta*. (× 1080.)

sion of chromidia from the nucleus and cytoplasm (Fig. 6, Text Fig. 2). These trophic granules have probably played an important part in the anabolism of the cells. They are normally distributed throughout the liver cells, but are especially numerous in the region of the food particles. They may be precipitately extruded from the cell (Text Fig. 2), or, like the protein food agglomerates, may degenerate into eosinophilic particles and add to the excretory wastes (Text Fig. 3).

A further pathological change in the nuclei of the protein cells is the formation of multipolar spindles (Text Fig. 4). Karyokinesis is not common in adult snail liver tissues but may be found. In pathological tissues such as these, normal mitoses are all but wanting, while abnormal divisions are common. Figures with three or four trophic centers are the most common. Amitotic division has not been seen.

All of these processes, which have mainly involved the more striking types of katabolism within the infected tissues, are accompanied by a degeneration of the cell walls, especially at the free end of the cells (Fig. 7), where the greatest concentration of toxic products occurs. However, it is an astonishing fact that snails, in which cytolytic changes have become very pronounced, are still able to feed and to carry on the digestive processes, although necessarily imperfectly.

It seems probable that the fluke cannot continue its existence indefinitely by parthenogenetic propagation, even when the circumstances are unfavorable for its migration or transference to another host. Under these circumstances the parthenita degenerates and the cercaria either encysts or works its way out of the snail. If encystment is to occur, the tail of the cercaria is thrown off and a cyst capsule is formed around the worm. This ameliorates the conditions of the host and a readjustment is effected. A hypertrophy of interstitial cells results around the cysts. Thus fibromata are formed in which melanin granules are frequently laid down (Fig. 4). This is the only way by which the snail is known to occlude foreign bodies. No calcification has been found in these fibromata. Meanwhile, the epithelial tissues are recuperated by rapid multipolar divisions of liver and "lime" cells basally and a sloughing off of the necrotic tissues into the lumen.

Among the secondary effects of the disease of the liver tissues brought about by these pathogenic organisms is the inability of the host to prevent such undigested food and feces as normally pass down the main digestive tract from entering the lumina of the liver. The poisoning of the tissues also involves the main digestive tube so that the cilia of the intestinal epithelium fail to function. Under these condition diatoms and algal filaments, together with particles of silica, frequently get into the ultimate tubules of the liver.

Although it has not been possible to determine any marked difference in the resistance of the various species of snails studied, there is evidence for the belief that certain flukes are much more harmful than others in their effects on the host. From a study of the cercariæ, the conclusion is reached that organs for mechanical injury, such as hooks and spines, are less likely to prove baneful to the host than the by-products of the worm. And while the excretory wastes set up a decidedly abnormal condition, the secretions of the mucin glands are probably the most injurious of all to the host. Such digestive secretions are commonly found to be present in echinostome cercariæ, stylet cercariæ and furcocercariæ. Certain species of furcocercariæ (*Cercaria gigas*, cercaria of *Schistosoma mansoni*) even have two physiologically different kinds of such digestive glands, those which are eosinophilic and those which are basophilic (Fig. 7). The protoplasm of the eosinophilic glands is deep red while the nuclei are basophilic. The basophilic mucin glands, on the other hand, take a deep hematoxylin stain throughout. The reaction of this latter type to Best's calcium-ammonium-carmin stain suggests that the granules around the nuclei of the cells are closely related to glycogen, while the material in the ducts gives a pure mucin reaction.

DISCUSSION

Since the liver of the mollusk possesses the properties of secretion, absorption and excretion in common with the vertebrate liver, and since the structure of the organ is in part similar in mollusk and vertebrate, it is profitable to inquire whether the study of the pathological conditions in the liver of the snail has a direct bearing on infected liver tissue of the vertebrate. This is especially worth while since some twelve adult species of flukes are known to give rise to pathological conditions in the liver of man.

First of all it is noteworthy that the fluke infection in the mollusk liver is by way of the blood system, while that of the great majority of parasitic infections of the vertebrate liver is by way of the bile-duct. Coccidiosis, hydatiditis, and most of the fluke infections arise from a previous lodgment of the parasite in the digestive tract, a migratory inflammation of the epithelium of the bile-duct as the infective agent forces its way up the duct, and finally the spreading of the disease throughout the trabeculæ of the liver. Then with the breaking down of the epithelial cells the matrix cells are invaded. Primary inflammation induced by such an invasion of animal parasites gives rise to a catarrhal condition of the epithelium, to an enlargement of the bile-duct and to a diffuse eosinophilia.

There are, however, a few common types of fluke parasitization of the vertebrate in which liver infection is not developed by way of the bile-duct but rather from the blood stream. In such infections the connective tissue surrounding the blood vessels is first attacked and the epithelium of the trabeculæ remains relatively untouched. This condition is followed by stasis of the portal vein and the development of granulomata around the infected area. As far as is known all of the blood flukes (including species of Schistosoma and Bilharziella) effect an entrance directly or indirectly into the blood stream and finally come to reside in the blood sinuses in the liver. Possibly also certain monostomes which live in the blood stream are at least temporary parasites of the liver tissues. Animals in this location can secure assimilable food much more readily than those in the lumen of the digestive tract or in its outpocketings.

Disregarding the means of entrance of the parasite and the primary pathological picture, there is a striking similarity in mollusk and vertebrate livers parasitized by flukes. Macroscopically both are distended and changed in color from the normal. Hypertrophy of the interstitial cells and desquamation of the epithelial cells occur in both, although in the opposite order. Hyperplasia, which is common in the vertebrate host, has not been seen in the mollusk liver. Edema and ascites may be found in both. The fluke in the blood sinus of the mollusk liver produces a recognizable stasis, just as *Fasciola hepatica* gives rise to bile stasis in the sheep and *Schistosoma japonicum* to portal stasis in man. Mechanical and chemico-pathological lesions are common in both instances. Melanin deposition in the connective tissue is a matter of record in mollusk and vertebrate liver. Necrosis is the ordinary fate of pathological tissues in every case where the infection is prolonged. And finally, with the migration of the pathogenic agent, rapid recovery of the organ by proliferation of new cells is the rule in mollusk and vertebrate liver alike.

On the whole, the mollusk liver seems able to withstand a heavier infection for a longer time than the vertebrate liver. It is also able to effect recovery much more readily. This suggests a greater power of adaptability and a larger regenerative index, based, no doubt, on a simpler organization.

SUMMARY

1. The tubular epithelium of the mollusk liver consists of two cytologically different kinds of cells, those with large nuclei and with closely aggregated opalescent granules in the cytoplasm (the "lime" cells), and those with small nuclei in which glycogen and fat are frequently found (the liver cells).

2. These two types of cells carry on secretive, absorptive and excretive processes in a manner similar in part to such processes in the vertebrate liver.

3. The liver tissues of many mollusks (mostly gasteropods) are infected with flukes which pass the parthenogenetic generations and the larval phase of the hermaphroditic generation in the mollusk. Heavy infections can usually be recognized by macroscopic inspection of the body after removal from the shell.

4. The flukes work their way to the liver through the blood sinuses, coming to reside in the interstices between the liver tubules. Here they mechanically irritate the host, requisition a large amount of digested foodstuffs, empty a burdensome amount of excretory wastes into the tissues, and cause serious cytolytic changes both in the epithelial cells of the tubules and in the intertubular connective tissue.

5. The pathological picture of the infected gasteropod liver is on the whole decidedly suggestive of the condition set up in the vertebrate liver infected with pathogenic organisms.

EXPLANATORY NOTE.—It was necessary in the absence of the author to reduce materially the length of this article and to make certain changes in the text. Figures 6 and 7 were drawn by Dr. Faust in color, but were replaced by copies in black and white. Responsibility for the changes in the manuscript and for the accuracy of the substituted drawings is therefore assumed by me.

It is with great pleasure that I acknowledge the counsel and cooperation of Mr. Brödel.

Ralph G. Mills, M. D.

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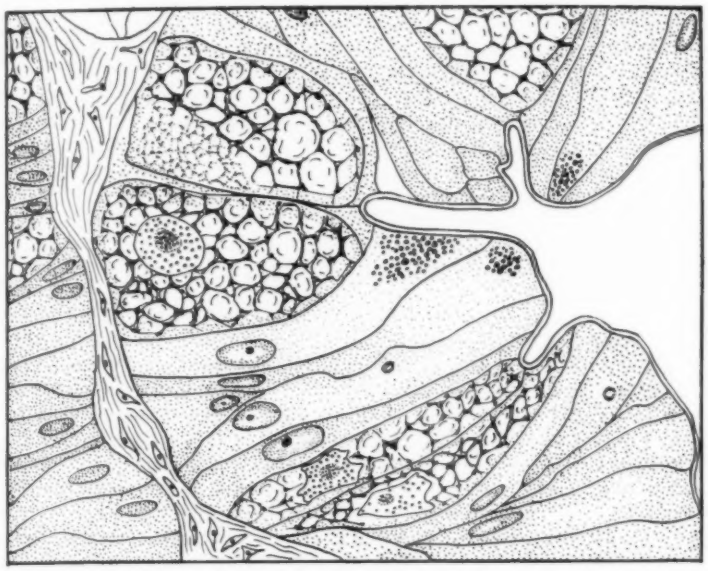

FIG. 1.—Normal liver tissue of *Planorbis trivolvis*, showing "lime" cells and liver cells of tubule, pseudo-cuticula lining the lumen of the tubule and the inter-tubular connective tissue. Note glycogen granules just beneath pseudo-cuticula. (× 810.)

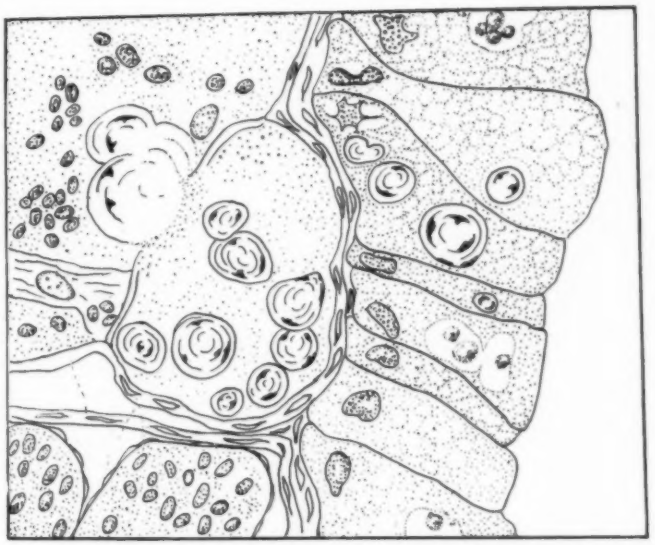

FIG. 3.—Effect of *Cercaria isocotylea* on *Pl. trivolvis*. Note passage of large masses of food from the epithelial cells into the parasite. (× 810.)

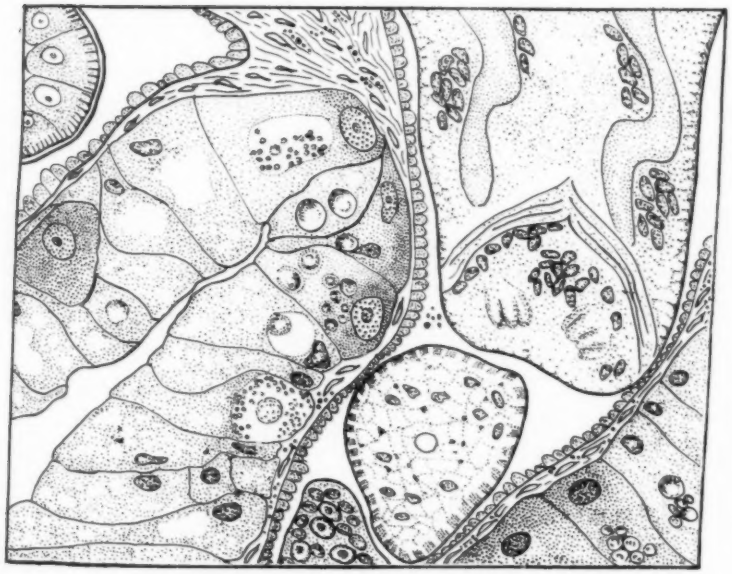

FIG. 2.—Pathological liver tissue of *Pl. trivolvis* infected with sporocysts and developing cercaria of *Cercaria gigas*. Note position of flukes in connective tissue. Epithelium of tubules highly vacuolated; glycogen only in connective tissue and in sporocysts. (× 810.)

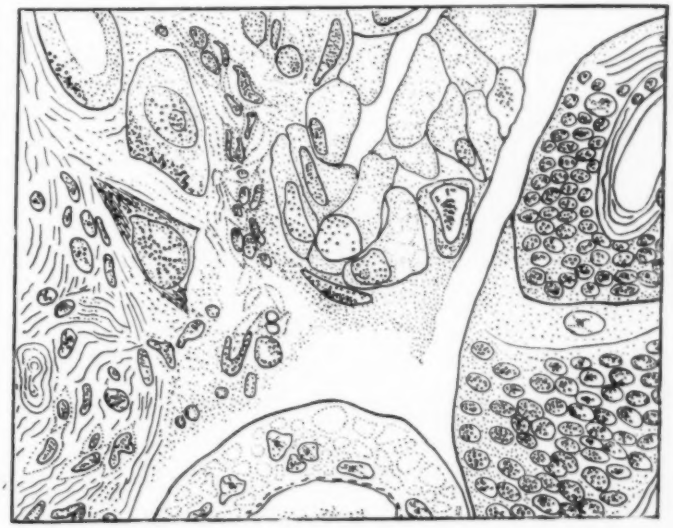

FIG. 4.—Late stage of infection of liver of *Pl. trivolvis* with *Cercaria convoluta*. Note hypertrophy of connective tissue, with fibromata. (× 810.)

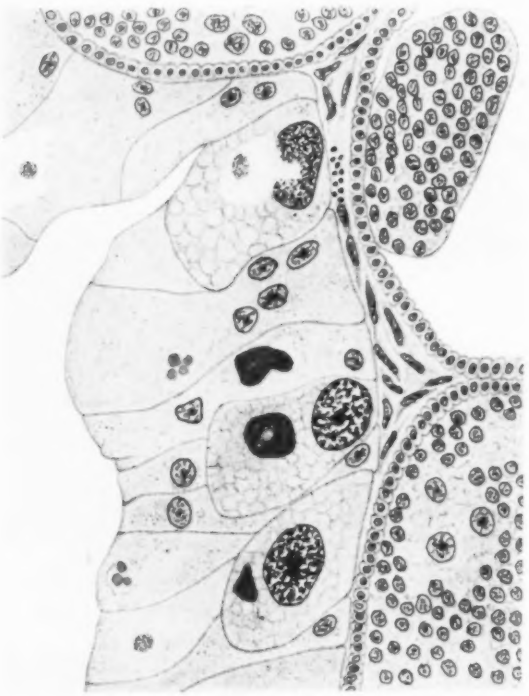

FIG. 5.—Effect of *Cercaria micropharynx* infection on liver epithelium of *Lymnaea proxima*. Note degeneration of nuclei and food reserves of protein-storage cells, excretory granule formation and eosinophilia at free end of epithelial cells (× 1080.)

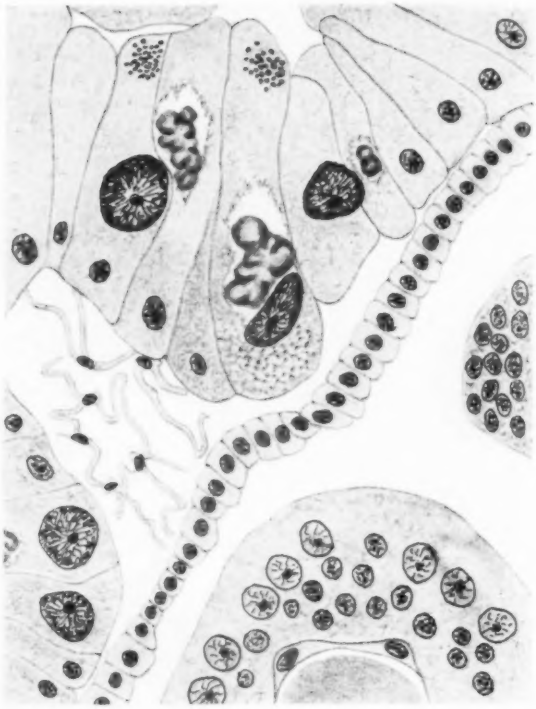

FIG. 6.—Liver tissue of *Goniobasis carinifera* infected with *Cercaria quatuor-solenata*. Note large agglomerations of excretory granules extrusion of chromidia, and general eosinophilia of epithelial cells. (× 1080.)

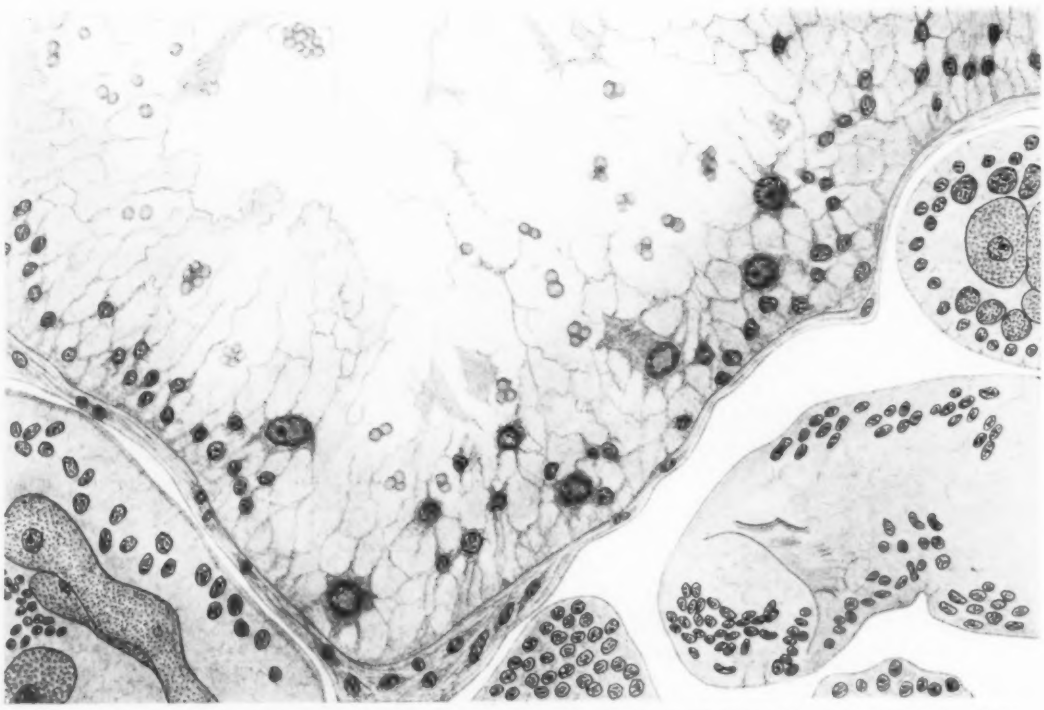

FIG. 7.—Effect of Cercaria of *Schistosoma mansoni* on liver tissue of *Planorbis guadelupensis*. Note heavy production of excretory granules, eosinophilia and general necrosis of cells. (× 1080.)

III. THE FATE OF INFLUENZA BACILLI INTRODUCED INTO THE UPPER AIR PASSAGES

By ARTHUR L. BLOOMFIELD

(From the Biological Division of the Medical Clinic, The Johns Hopkins University and Hospital)

In previous papers [1] we reported observations on the fate of certain bacteria after their introduction into various parts of the upper air passages. This work represented a portion of a systematic study of one phase of infection, namely, the period from the arrival of the organism at the mouth or nose until it is eliminated or until disease is produced. *Sarcina lutea, B. coli,* and *Staph. albus* were studied. It was found that these bacteria were rapidly disposed of; *Sarcina* was promptly destroyed by the saliva, and *B. coli* and *Staph. albus* were washed away by mechanical processes without showing any tendency to colonize. The present report deals with a similar study of the hemoglobinophilic bacteria (*B. influenzæ*). No attempt was made to produce disease, and our purpose was simply to study the fate of the organisms and the method of their disposal.

LITERATURE

Several records of inoculations of human beings with *B. influenzæ* are found in the recent literature. These experiments were all made on the hypothesis that the organisms used might be the cause of epidemic influenza and in the attempt to demonstrate this fact by the production of disease. Rosenau [2] introduced strains of influenza bacilli freshly isolated from cases of epidemic influenza into the throats of volunteers without producing any local or general disease. Sellards and Sturm,[3] in the course of a study of hemophilic bacilli isolated from cases of measles, sprayed a saline emulsion of five strains upon the mucous membranes of the eye, nose and throat of four volunteers. Cultures made at three-day intervals for a period of two weeks were uniformly negative, and no local or general symptoms were produced. Sellards reports no observations made during the first three days after inoculation. Wahl, White and Lyall [4] found that the application to the mucous membrane of the nares and naso-pharynx of a saline emulsion of strains from cases of epidemic influenza failed to produce any abnormal symptoms in five healthy men. These workers were unable to recover *B. influenzæ* from the nose after 48 hours except in one case, but found the organisms present in the naso-pharynx for two weeks or longer. In some cases the bacteria disappeared after a few days to return later. In summary, then, the above experiments, while indicating the general trend of events, give no detailed information about the immediate and exact fate of the influenza bacillus.

METHODS

Strains.—Until the needs of the recent epidemic stimulated the development of media satisfactory for the growth of *B. influenzæ,* little success had been met with in the study of the finer details of its natural history or in the differentiation of strains by biological or other methods. All small Gram-negative hemophilic bacilli isolated from the respiratory passages were placed together in one group. Recent work, however, particularly that of Rivers,[5] suggests that all the organisms previously included under one head are by no means identical, but that they represent various groups differing in essential biological characteristics. It is therefore impossible to be certain now of the exact nature of the original organism of Pfeiffer as well as of the nature and identity of the "influenza bacilli" which were so prominent in the cases of epidemic disease in 1918.

Three strains were employed in the present work. They were all isolated from the throats of healthy men,* and conformed to all the usual criteria of the influenza bacillus group.

Media.—In view of the difficulty of growing influenza bacilli under unfavorable conditions, the utmost care was used in the preparation of the media. Fresh 2 per cent meat infusion agar (pH 7.3 to 7.5) to which 1 per cent of fresh defibrinated rabbit's blood was added, or the sodium oleate hemoglobin agar of Avery were used in all the work. The medium was always fresh and moist, and each lot was tested by inoculation with the various strains. It was considered unsatisfactory unless the colonies were large and reached their maximum growth in from 24 to 36 hours.

Inoculations.—As in the previous work, healthy individuals presenting no unusual abnormality of the upper air passages were used. The whole 24-hour growth from an agar slant was collected on a loop and deposited on the desired site—the tongue, nasal septum, naso-pharynx or tonsil crypt. Cultures were made at various intervals by scraping the site of inoculation with a platinum loop or (in the case of the naso-pharynx) by means of the usual cotton swab. The material collected was spread with a glass rod over two plates. It was regarded as essential that the spread of colonies be discreet; plates covered by a confluent mass of growth are useless in work of this sort. The cultures were studied after from 24 to 48 hours, and in every case the diagnosis of *B. influenzæ* was established by isolation of the organism in pure culture. Great care was taken in estimating the quantitative relations.

The site of inoculation was watched for signs of reaction. In no case was there any change in the appearance of the mucosa, or any constitutional reaction.

EXPERIMENTS

EXP. I.—Fate of influenza bacilli swabbed on the tongue. The bacteria were placed on the tongue, and cultures were made from the tongue and from the pharynx at various intervals. The results are summarized in Table I.

***Summary.*—Influenza bacilli swabbed on the tongue in large amounts were promptly spread over the mouth cavity. The**

* We are indebted to Dr. Rivers for these strains.

TABLE I.—FATE OF B. INFLUENZ.E SWABBED ON THE TONGUE

Name	Date	Procedure	Number of colonies of B. influenzæ per plate recovered from tongue and pharynx												Control culture before inoculation	
			Tongue						Pharynx							
			After 10 min.	After 2 hrs.	After 1 day	After 2 days	After 3 days	After 4 days	After 10 min.	After 2 hrs.	After 1 day	After 2 days	After 3 days	After 4 days.	Tongue	Pharynx
M.	Nov. 10.	One slant strain 55 B. swabbed on anterior half of tongue.	∞*	A good many colonies B. infl.	A very few colonies B. infl.	No B. infl.	....	....	A good many colonies B. infl.	No B. infl.	No B. infl.	No B. infl.	....	....	No B. infl.	A few cols. B. infl.
J.	Nov. 16.	One slant strain 55 B. swabbed on anterior half of tongue.	∞	A very few cols. B. infl.	No B. infl. found.	....	....	No B. infl.	∞	150 cols. B. infl.	20 cols. B. infl.	.....	....	No B. infl.	No B. infl.	A few cols. B. infl.
C.	Nov. 17.	One slant strain 63 swabbed on anterior half of tongue.	∞	150 cols. B. infl.	No B. infl.	....	....	....	A few cols. B. infl.	A few cols. B. infl.	No B. infl.	.....	....	....	No B. infl.	No B. infl.
B.	Nov. 17.	One slant strain 33 swabbed on anterior half of tongue.	∞	A few cols. B. infl.	No B. infl.	....	....	....	Many cols. B. infl.	A few cols. B. infl.	No B. infl.	.....	....	....	No B. infl.	No B. infl.

* ∞ = innumerable.

TABLE II.—THE FATE OF INFLUENZA BACILLI INTRODUCED INTO THE NOSE

Name	Date	Procedure	Number of colonies of B. influenzæ per plate recovered from nose and pharynx										Control culture before inoculation	
			Nose				Pharynx							
			After 10 min.	After 2 hrs.	After 1 day	After 2 days	After 10 min.	After 2 hrs.	After 1 day	After 2 days	After 4 days	After 8 days	Nose	Pharynx
C.	Nov. 11.	One slant strain 56 B. swabbed on left nasal septum.	∞	∞	1000 cols. B. infl.	No B. infl.	.....	A few cols. B. infl.	No B. infl.	No B. infl.	.....	.....	No B. infl.	A few cols. B. infl.
S.	Nov. 12.	One slant strain 55 B. swabbed on left nasal septum.	∞	200 cols. B. infl.	No B. infl.	No B. infl.	.....	No B. infl.	A few cols. B. infl.	About 50 cols. B. infl.*	.....	No B. infl.	No B. infl.	No B. infl.
St.	Nov. 13.	One slant strain 55 B. swabbed on left nasal septum.	∞	200 cols. B. infl.	20 cols. B. infl.	No B. infl.	.....	No B. infl.	No B. infl.	No B. infl.	.....	.....	No B. infl.	No B. infl.
Ch.	Nov. 18.	One slant strain 63 swabbed on right nasal septum.	∞	50 cols. B. infl	No B. infl.	.....	.....	About 20 cols. B. infl.	No B. infl.	.....	.....	.....	No B. infl.	A few cols. B. infl.
B.	Nov. 19.	One slant strain 33 swabbed on left nasal septum.	∞	Several hundred cols. B. infl.	No B. infl.	.....	.....	No B. infl.	No B. infl.	.....	.....	.....	No B. infl.	No B. infl.

* This strain was not 55 B. (See Table V.)

TABLE III.—FATE OF INFLUENZA BACILLI INTRODUCED INTO TONSIL CRYPTS

Name	Date	Procedure	Number of colonies per plate of B. influenzæ recovered from crypt and pharynx													Control culture before inoculation	
			Crypt							Pharynx							
			After 10 min.	After 2 hrs.	After 1 day	After 2 days	After 4 days	After 6 days	After 8 days	After 10 min.	After 2 hrs.	After 1 day	After 2 days	After 4 days	After 6 days	After 8 days	Crypt	Pharynx
Co.	Nov. 25.	One loop strain 33 placed in a tonsil crypt.	300 cols. B. infl.	10 cols. B. infl.	No B. infl.	....	....	...	....	Many cols. B. infl.	Many cols. B. infl.	No B. infl.	.....	.....	.....	.....	No B. infl.	No B. infl.
H.	Nov. 29.	One loop strain 63 placed in a tonsil crypt.	∞	∞	....	100* cols. B. infl.	200* cols. B. infl.	No B. infl.	No B. infl.	Several hundred cols. B. infl.	Several hundred cols. B. infl.	....	Several* hundred cols. B. infl.	Several* hundred cols. B. infl.	About* 100 cols. B. infl.	About* 100 cols. B. infl.	No B. infl.	A few cols. B. infl.
W.	Dec. 6.	One loop strain 55 B. placed in a tonsil crypt.	About 100 cols. B. infl.	A few cols. B. infl.	No B. infl.	....	....	....	....	Many cols. B. infl.	A few cols. B. infl.	No B. infl.	.....	.....	.....	.....	No B. infl.	No B. infl.

* Not strain 63. (See Table V.)

organisms disappeared both from the tongue and pharynx very rapidly. After two hours the number recovered was much reduced, and after 24 hours only a very few organisms were obtained in two out of four cases. Control cultures before inoculation yielded a very few colonies from the pharynx in two cases. The general result of this experiment is that in 24 to 48 hours the inoculated organisms have disappeared or at least been reduced to the number "normally" present in the pharynx. There was no local or general reaction following inoculation.

EXP. II.—Fate of influenza bacilli introduced into the nose. The bacteria were deposited on the nasal septum behind the vestibule and cultures were made at various intervals from the nose and pharynx. The results are summarized in Table II.

Summary.—Large numbers of *B. influenzæ* swabbed on the nasal septum disappeared rapidly from the site of inoculation. None could be recovered after 48 hours. Simultaneous cultures from the pharynx in three of five cases yielded a few colonies of *B. influenzæ* in from two hours to 24 hours after inoculation. In one case (S.) 50 colonies were recovered from the pharynx in the 48-hour culture, but this organism was found to be a different strain from that introduced (see Table V).

EXP. III.—Fate of influenza bacilli introduced into tonsil crypts. The bacteria were introduced into a tonsil crypt with a platinum loop and cultures were made at various intervals from the crypt and from the pharynx. The results are summarized in Table III.

Summary.—Influenza bacilli introduced into tonsil crypts could not be recovered from the site of inoculation after 24 hours in two of three cases. In the third case influenza bacilli were recovered after two and also after four days, but they were found to be different strains from those introduced (see Table V). In this case influenza bacilli were also recovered from the pharynx several days after inoculation, but the strain was not only different from that introduced, but it was also different from that obtained from the crypt after two and after four days (see Table V).

EXP. IV.—Fate of influenza bacilli introduced into the naso-pharynx. Influenza bacilli were swabbed on the naso-pharynx and cultures were made at various intervals. The results are summarized in Table IV.

Summary.—Influenza bacilli swabbed in large amounts on the naso-pharynx disappeared very rapidly. After two hours very few organisms could be recovered from the site of inoculation. In one case, influenza bacilli recovered after one and after four days were different strains from those introduced (see Table V).

DISCUSSION

The general result of these experiments seems to indicate two facts: First, that several strains belonging to the group of so-called influenza bacilli swabbed in large amounts on the normal mucous membranes of the upper air passages failed to colonize and disappeared in about a day; and secondly, that in no case did they produce any demonstrable local lesion or general reaction.

In five instances influenza bacilli were recovered at periods later than 24 hours after inoculation. It seemed of importance to determine whether these strains were identical with those introduced or whether the strain introduced had disappeared and another had supplanted it. Biological differential methods worked out by Dr. Rivers were applied by him to the study of these cultures. In every case it was possible to show that the strain introduced had been replaced by organisms possessing different characteristics (see Table V). It seems desirable to bring these findings into relation with the known facts about the presence of influenza bacilli in the throats of healthy people. Winchell and Stillman [8] review the recent literature on this subject and report careful studies of their own on a series of individuals over a period of eight months. It seems quite certain that hemophilic bacilli may be found in from 40 to 80 per cent of various groups of healthy people. The exact seat of bacterial multiplication in the pharynx and the length of time over which any given strain persists are however unknown. Our experiments suggest that the free surfaces of the normal mucous membranes present a relatively unfavorable environment for these bacilli to colonize upon. It may be that their source in certain cases is a focus, such as a chronic sinusitis, bronchitis, or bronchiectasis, or an acute infection of the respiratory tract either in the same or in another individual from which they are discharged into the open pharyngeal cavity. It should be emphasized that all studies on the persistence of influenza bacilli in the throat are of uncertain significance in the absence of proof that the strains recovered from the same individual at various times are identical. The final solution of this question must await the development of complete and accurate methods of differentiating the various strains of hemophilic bacilli.

Inasmuch as the organisms employed in our experiments had been grown on artificial media for several generations the objection may be raised that their failure to colonize was due to alteration in their virulence by growth outside the body. This objection cannot be answered and the experiments are presented with this in mind.

THE MECHANISM OF DISPOSAL OF *B. INFLUENZÆ*

As in the case of the organisms previously studied an attempt was made to analyze the various factors which might be responsible for the disposal of *B. influenzæ*.

1. *The Antagonistic Action of Other Bacteria in the Mouth and Throat.*—No direct experimental method was available for determining to what extent the growth and multiplication of *B. influenzæ* in the throat is prevented by bacteria already present. It is known that *B. influenzæ* grows well on artificial media in symbiosis with many other bacteria under proper quantitative relations. It may, however, be rapidly overgrown by an excess of other bacteria which in smaller numbers would favor its growth. In the case of nasal inoculations other bacteria can hardly play an important part since the nasal mucosa is practically free of organisms.

2. *The Effect of the Mouth Secretions.*—An attempt was made to reproduce mouth conditions by testing the effect of saliva on influenza bacilli in the test tube. Fresh saliva was centrifuged at high speed for a few minutes to remove gross particles. Small amounts of the resulting clear fluid were placed in test tubes and heavily inoculated with *B. influenzæ*. The entire growth from an agar slant was suspended in 0.5 c. c. of saliva, and control tubes of plain broth were similarly inoculated. Cultures were made at various intervals on oleate hemoglobin agar plates. Three salivas covering the normal

TABLE IV.—FATE OF INFLUENZA BACILLI INTRODUCED INTO THE NASO-PHARYNX

Name	Date	Procedure	Number of colonies per plate recovered from naso-pharynx					Control culture before inoculation
			After 10 min.	After 2 hrs.	After 1 day	After 2 days	After 3 days	
W.	Dec. 1.	One slant of strain 33 swabbed on naso-pharynx.	∞	200 cols. B. infl.	No B. infl.	No B. infl.	.....	No B. infl.
R.	Dec. 1.	One slant of strain 33 swabbed on naso-pharynx.	∞	10 cols. B. infl.	A very few* cols. B. infl.	.....	4 cols. B. infl.*	No B. infl.

* Not the strain which was introduced. (See Table V.)

TABLE V.—COMPARISON OF CHARACTERISTICS OF STRAINS OF INFLUENZA BACILLI INTRODUCED AND RECOVERED IN VARIOUS CASES

Name	Characteristics of	Morphology	Staining	Hemoglobinophilia	Hemolysis	Indol formation	Nitrite formation	Agglutination with stock serum
Sp.	Strain introduced (55 B).	Small regular bacilli.	Gram-neg.	Hemoglobinophilic	Non-hemolytic.	*Marked.*	Marked.	+
	Strain recovered from throat 48 hrs. after inoculation.	Small regular bacilli.	Gram-neg.	Hemoglobinophilic	Non-hemolytic.	*None.*	Marked.	0
Ha.	Strain introduced (63).	Small regular bacilli.	Gram-neg.	Hemoglobinophilic	*Non-hemolytic.*	*None.*	Marked.	0
	Strain recovered from throat 4 days after inoculation.	Small regular bacilli.	Gram-neg.	Hemoglobinophilic	Non-hemolytic.	*Marked.*	Marked.	0
	Strain recovered from crypt 4 days after inoculation.	Large thick bacilli.	Gram-neg.	Hemoglobinophilic	*Hemolytic.*	*Marked.*	Marked.	0
R.	Strain introduced (33).	Small regular bacilli.	Gram-neg.	Hemoglobinophilic	Non-hemolytic.	*Marked.*	Marked.	0
	Strain recovered from throat 24 hrs. after inoculation.	Very large numerous threads.	Gram-neg.	Hemoglobinophilic	Non-hemolytic.	*None.*	Marked.	0
	Strain recovered from throat 3 days after inoculation.	.....	Gram-neg.	Hemoglobinophilic	Non-hemolytic.	*None.*	Marked.	0

TABLE VI.—EFFECT OF SALIVA ON INFLUENZA BACILLI

Date	pH. of saliva	Strain of B. infl.	Time of culture after inoculation	0.5 c. c. broth and growth from one slant B. infl.	0.5 c. c. saliva and growth from one slant B. infl.
Dec. 6.	7.0	55 B.	Immediately.	Innumerable cols. B. influenzæ.	About 50 cols. "mouth bacteria" per plate + innumerable cols. B. influenzæ.
			After 2 hrs.	Innumerable cols. B. influenzæ.	About 50 cols. "mouth bacteria" per plate + innumerable cols. B. influenzæ.
			After 24 hrs.	Innumerable cols. B. influenzæ. (About same number as in previous culture.)	About 300 cols. "mouth bacteria." *No* B. influenzæ.
Dec. 6.	7.0	33	Immediately.	.....	About 100 cols. "mouth bacteria" per plate + innumerable cols B. influenzæ.
			After 2 hrs.	.....	About 75 cols. "mouth bacteria" per plate + innumerable cols. B. influenzæ.
			After 24 hrs.	.....	About 500 cols. "mouth bacteria" per plate. *No* B. influenzæ.
Dec. 3.	7.3	63	Immediately.	.....	About 300 cols. "mouth bacteria" per plate + innumerable B. influenzæ.
			After 2 hrs.	.....	About 300 cols. "mouth bacteria" per plate + innumerable B. influenzæ.
			After 24 hrs.	.....	About 300 cols. "mouth bacteria" per plate. *No* B. influenzæ.
Dec. 3.	7.3	33	Immediately.	.....	About 50 cols. "mouth bacteria" per plate + innumerable B. influenzæ.
			After 2 hrs.	.....	About 75 cols. "mouth bacteria" per plate + innumerable B. influenzæ.
			After 24 hrs.	.....	About 500 cols. "mouth bacteria" per plate. *No* B. influenzæ.
Dec. 4.	6.4	55 B.	Immediately.	.....	About 100 cols. "mouth bacteria" per plate + innumerable B. influenzæ.
			After 2 hrs.	.....	About 75 cols. "mouth bacteria" per plate + innumerable B. influenzæ.
			After 24 hrs.	.....	About 100 cols. "mouth bacteria" per plate. *No* B. influenzæ.

range of reaction (pH 6.4 to pH 7.3), and three strains of influenza bacilli were employed. The results are summarized in Table VI.

This experiment shows the following points. Influenza bacilli suspended in plain meat infusion broth were viable at the end of 24 hours. From saliva inoculated with the same amount of culture living influenza bacilli were recovered after two hours, but not after 24 hours. The proportion of mouth bacteria in the saliva to the inoculated influenza bacilli was about 1 to 10,000 at the beginning of the experiment. At the end of 24 hours there was only a slight increase in the number of mouth bacteria, whereas no influenza bacilli grew. The experiment seems therefore to indicate that while saliva exercises no immediate destructive effect on *B. influenzæ*, it is an unfavorable medium for the growth of these bacteria and that they do not remain viable in this medium for as long as 24 hours. This result was constant with salivas of different pH.

The probable explanation, therefore, of the rapid disappearance of *B. influenzæ* when introduced into the normal upper air passages involves both the action of a medium unfavorable for the growth of these organisms, together with the mechanical flushing processes constantly at work in these regions.

The question naturally arises in this connection as to what makes possible the tremendous growth of influenza bacilli in disease conditions, such as acute sinusitis pharyngitis, laryngitis, pneumonia, measles, influenza, etc. A possible explanation which still lacks final proof is that these acute processes may alter the environment in such a way that the organisms take hold and grow rapidly at the seat of disease.

SUMMARY

1. Three strains of influenza bacilli introduced in large amounts into the normal upper air passages disappeared very rapidly—within from one to two days. In no case was a carrier state produced.

2. In no case did any local or general pathological process result from such inoculation.

3. In five instances influenza bacilli isolated later than 24 hours after inoculation were shown to be different strains from those introduced.

4. Influenza bacilli were no longer viable after being suspended in saliva for 24 hours at 37°C.

5. The rapid disappearance of influenza bacilli from the upper air passages is probably due to the combination of an unfavorable environment with the mechanical flushing processes at work in these regions.

6. The question of the persistence of influenza bacilli in normal throats cannot be finally settled until we possess accurate methods for differentiating various strains of hemophilic bacteria.

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NOTES ON MUSCULAR WORK DURING HYPNOSIS

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The novel conditions of modern warfare have directed attention to the extraordinary occurrence of the functional nervous and mental disturbances. With one-third of all discharges for disability in the British Army due to war neuroses or so-called "shell shock," these disorders became a grave medico-military problem calling for urgent therapeutic solution. Treatment with rest, re-education, psycho-analysis, occupational therapy and hypnosis was and still is being tried, but from reports in the British and French medical journals it would appear that the most encouraging results are obtained with the aid of suggestion and hypnosis.

Unfortunately, however, our knowledge of hypnotism is very incomplete, and if it is to be used intelligently as an effective means of analyzing and treating these conditions, it is necessary that it be given a sound physiological foundation. Thus far there have been scarcely any carefully conducted laboratory experiments to determine the underlying physiology of hypnosis. What data we have are in large part unsupported by experimental proof—a deficiency which obviously lessens its scientific worth. Valuable contributions have been made to the subject, it is true, by such men as Vogt, Forel, Bernheim, Moll and others, but these are concerned mainly with the therapeutic application and general psychology of hyp-

* It is a deep sorrow that along with the appearance of this article we must record the untimely death of the author. The son of the Reverend J. C. Nicholson, pastor of Madison Square Methodist Episcopal Church, but 28 years old, Nicholson had shown himself a man of unusual energy and promise. He was one of those who early in his student years had manifested an interest in study and research the first-fruits of which were published in an article with Dr. Emil Goetsch, in the American Review of Tuberculosis, in 1919. Obliged early in January, 1918, to interrupt his studies because of ill health, his energy and enthusiasm were undiminished. In the fall of 1919 he returned, himself again physically and full of activity and devotion to his chosen career. In his death his friends and his teachers mourn the loss of an active, inquiring mind, which gave promise of happy fruition. W. S. T.

notism. Nowhere, in fact, has there been any consistent program aiming to get at the subject by the method of laboratory experimentation. It therefore occurred to the writer that the time was ripe to bring to bear on the problem the modern technique of the physiological laboratory and thus to obtain a series of exact objective records of just what effect hypnosis and suggestion have on the body mechanism of man. The completed investigation will aim naturally to answer the following questions: What is the condition of the muscular, the nervous, the cardio-respiratory, the gastro-intestinal, the endocrine and the excretory systems in the hypnotic sleep and how can these systems be influenced by suggestion? Notes on the different phases of the work will be published as they are completed. This preliminary report concerns only the results of certain studies on the muscular system.

As we wished to determine the effects of suggestion upon muscular efficiency and record the findings objectively, a Mosso ergograph was used as the instrument best adapted to fulfil these requirements. With this apparatus one arm and one hand are so fixed by straps and metal supports that it is possible to test the efficiency of a small group of muscles. The person experimented upon makes a series of short contractions of the flexor muscles of the middle finger, thereby lifting a known weight to a definite height which is recorded upon a drum. In a set of experiments the rate of the series of contractions, that is, the interval of rest between the contractions, is kept constant as also is the load lifted. Under these conditions a fully awake subject makes contractions which become less and less extensive as fatigue comes on, until finally, despite the strongest voluntary effort, the contractions of the muscles are insufficient to lift the weight. In this way a record is obtained, such as is shown in Fig. 1, and the capacity for work of the muscle used can be studied objectively under varying conditions and permanent records secured. The contractions in the experiments here reported were timed by a metronome so that they occurred at regular intervals of two seconds. Any irregularity in the rate of revolution of the drum, that is, any difference in the spacing between the separate lines in the records may therefore be disregarded. The weight used was one of three kilograms.

The objection might be advanced that with the Mosso ergograph we cannot compute the total amount of work which the muscle is capable of performing, as would be possible if we were to use a spring ergograph. But a consideration of the nature of our problem will show that relative results are adequate for our purposes and that the ergograph of Mosso is therefore best suited for these experiments.

Only those subjects were used whom I could place in the deepest hypnotic sleep—the state characterized by cataleptic rigidity.[1] Having selected the subjects, it was necessary to determine the normal work capacity of each one as measured by the ergograph. Accordingly, for a period of two weeks daily tracings were obtained until an approximately standard curve of work for each subject in the waking condition was established. Fig. 1 represents such a standard work-curve requiring approximately 10 minutes to complete. The next step was to determine the normal recuperative period, that is, the length of time necessary to enable the subject to repeat the amount of work just recorded and thus reproduce a tracing as extensive as the first. This period varied with the different subjects, but was never more than two nor less than one hour.

With these standards determined for the waking state we proceeded to compare them with the results obtained in the hypnotic sleep. A similar procedure was followed for each subject as follows:

Exp. I.—Subject hypnotized and given suggestions, throughout the period of work, of increased energy and muscular power with absence of fatigue sensations, and the results recorded (Fig. 2). The subject was awakened when the tracing had extended around the circumference of the drum, which generally took about 20 minutes.

Exp. II.—In this experiment an answer was sought to the question: How much work is the fully awake subject capable of performing immediately after the work done in hypnosis? That is, a tracing was made of his work capacity as soon after the completion of Experiment I as a fresh drum could be put in place—about three minutes (Fig. 3).

Exp. III.—Subject again hypnotized at the conclusion of Experiment II and a second tracing in the hypnotic sleep recorded at once (Fig. 4).

Exp. IV.—Subject while fully awake was permitted to work almost up to the point of fatigue and while still working he was hypnotized and thus in one tracing the contrast between work in the waking and hypnotic sleep was recorded (Fig. 5, *A* and *B*).

Exp. V.—Subject was permitted to work almost up to the point of fatigue, but at the point where in the previous experiment hypnosis had been induced suggestions were now made without hypnosis of increased muscular power, no fatigue sensations, etc. (Fig. 6, *A* and *B*).

RESULTS

The records obtained show that a very definite increase in muscular efficiency can be obtained by suggestion in the hypnotic state and that suggestions given even while the subject is fully awake influence muscular efficiency to some extent. The increased efficiency during hypnosis shows itself in three ways: First, by an increase in the actual amount of work done (Figs. 2, 4, 7). In fact, during the hypnotic sleep the capacity for work seemed practically endless, as we invariably had to conclude the experiment because of the limited recording surface of our drum. Further work along this line is of course essential. The records secured so far afford, however, an affirmative answer to the question: Can suggestions during hypnosis increase work capacity? Second, by an increase in endurance (Figs. 2, 4, 7). Third, by a decrease in fatigue, both subjective and objective. After work in the hypnotic sleep the subjects never complained of any fatigue, nor could questioning elicit any signs of fatigue, whereas after performing a much smaller amount of work in the waking condition they frequently complained of being quite tired and exhausted and always on being questioned stated they were fatigued. The records (Figs. 2, 4, 7) show the absence of any objective fatigue, but this point was brought

[1] In all of the experiments the hypnotizing was done by the author.

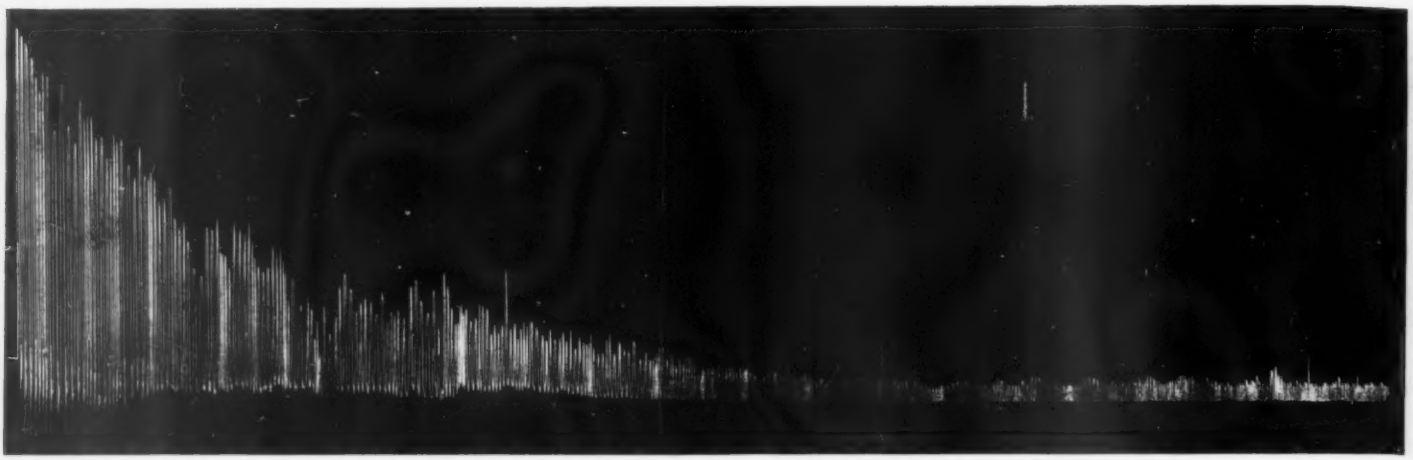


FIG. 1.—Standard fatigue curve of subject when fully awake. It requires a rest period of one hour to enable the subject to duplicate this amount of work.

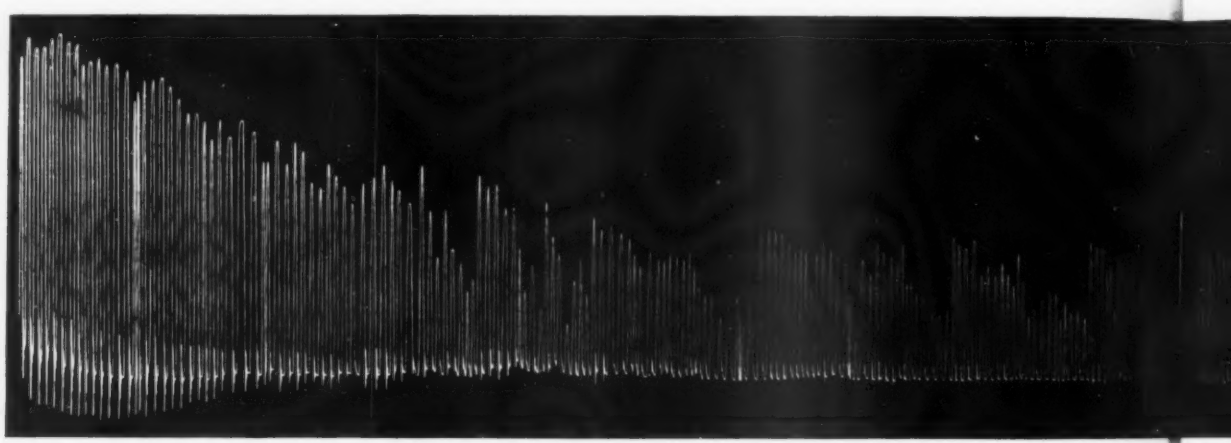


FIG. 2.—Fatigue curve made during hypnosis one hour after completion of Fig. 1. The work was interrupted and the ...g bro... of work done under hypnosis.

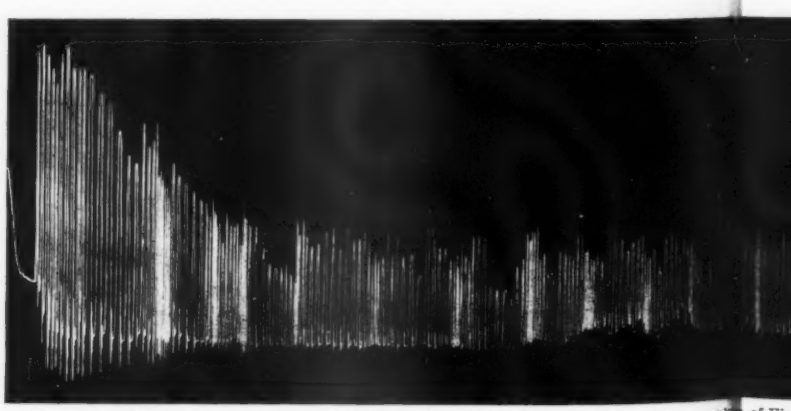
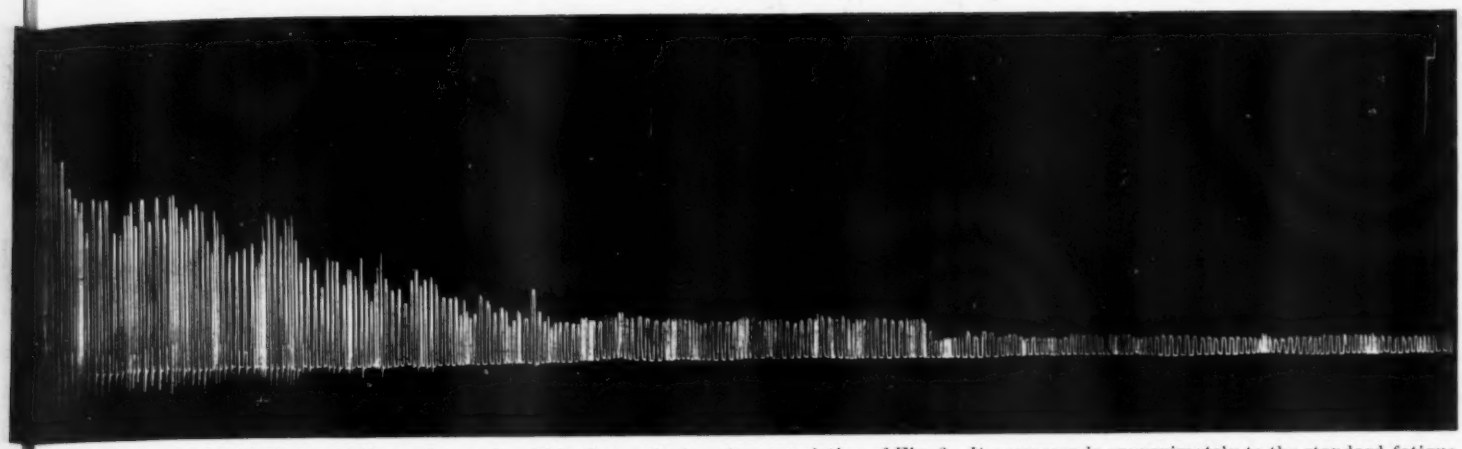
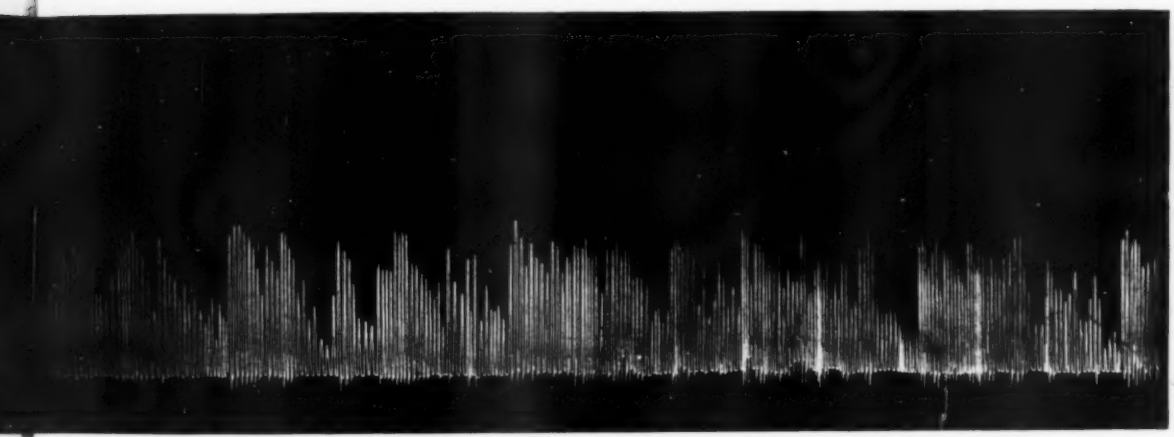


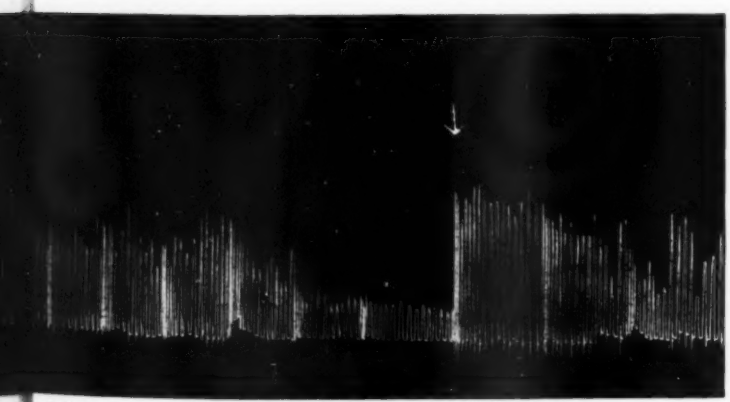
FIG. 4.—Fatigue curve made during hypnosis within five minutes after compl... of Fig... an increased muscular efficiency during hypnosis even though the subject just ...viously ... indicates the point at which suggestions of renewed energy were made.



3.—Fatigue curve of subject when fully awake, made within three minutes after completion of Fig. 2. It corresponds approximately to the standard fatigue (Fig. 1) and shows the absence of fatigue after work done during hypnosis.



brought to an end because of the limited recording surface of the drum. It demonstrates the much greater amount



of Fig. 3. Experiment concluded when it was clear that the tracing showed viously had worked to the limit of his capacity while fully awake. The arrow

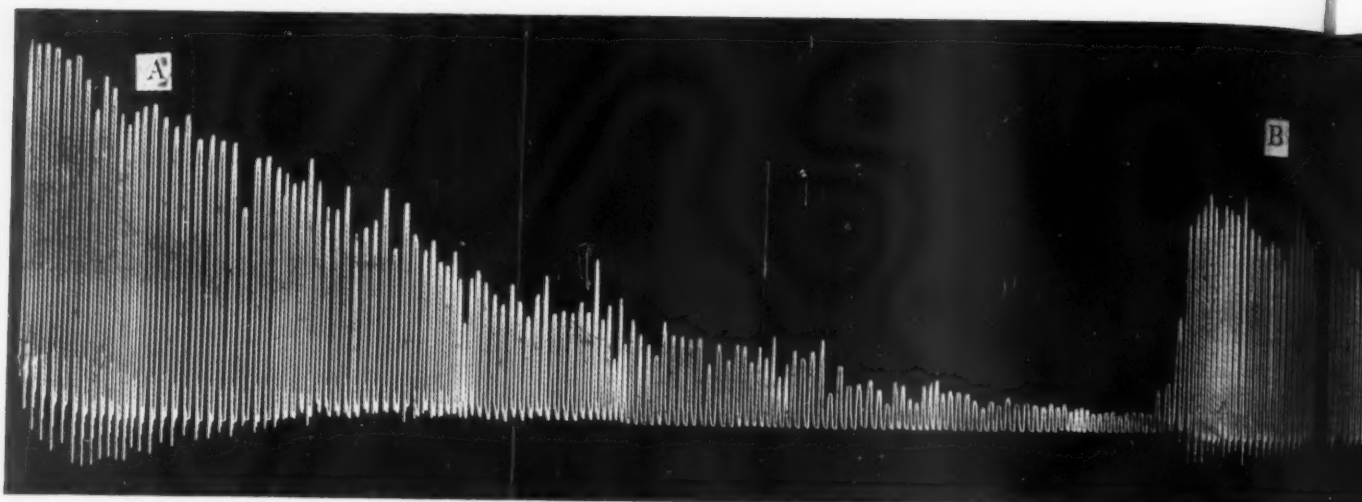


FIG. 5.—In the first half of this tracing (*A*) the subject is fully awake. The record shows a typical fatigue curve. At the point where it appare shows the increased work done during hypnosis.

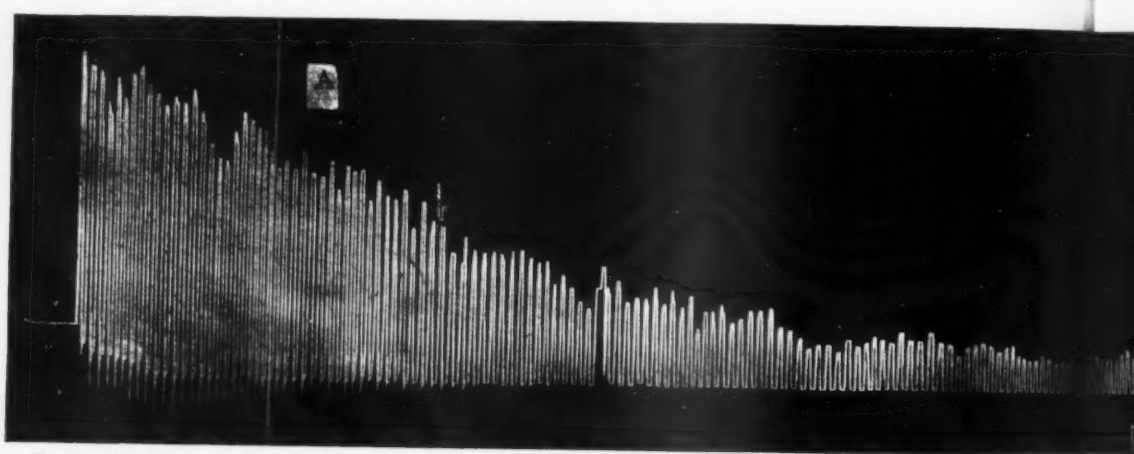


FIG. 6.—In this, as in the previous figure, the subject is permitted to work almost to the point of exhaustion, but here in t the same kind as were given previously during hypnosis. The two arrows indicate the points at which suggestions we made. marked contrast to that obtained from hypnotic suggestion (Fig. 5).

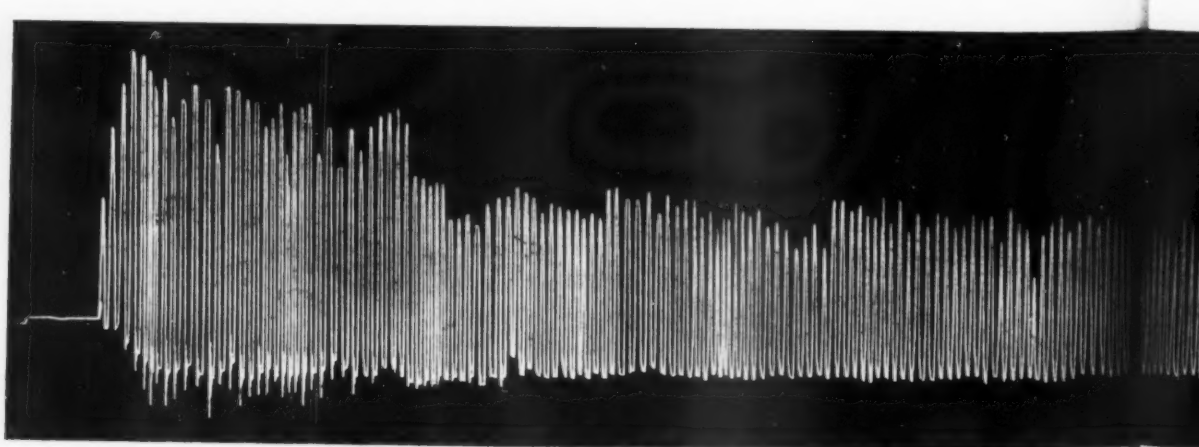
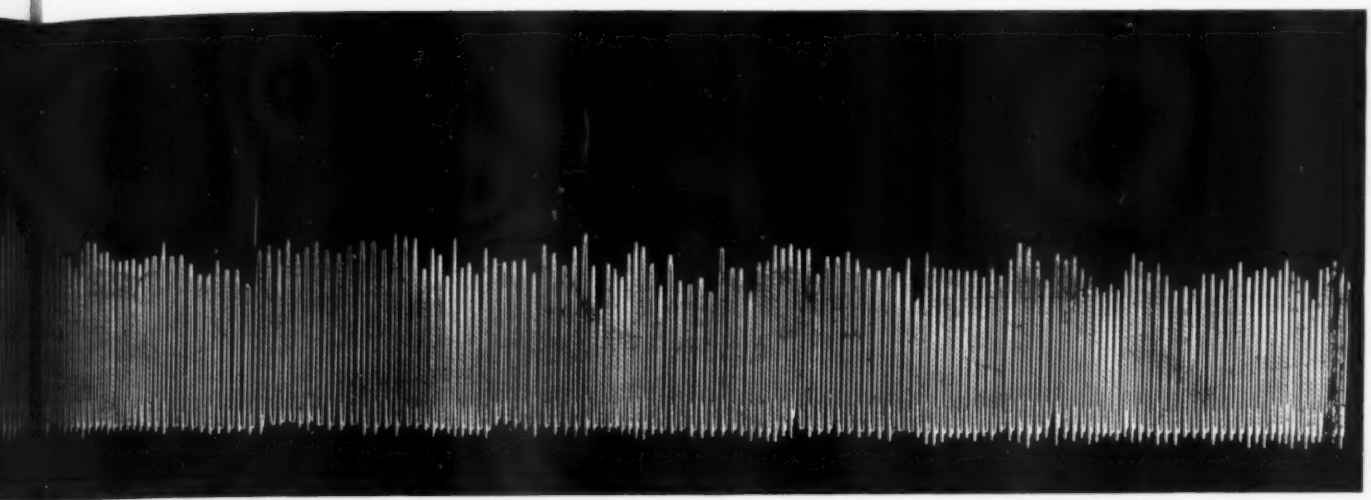
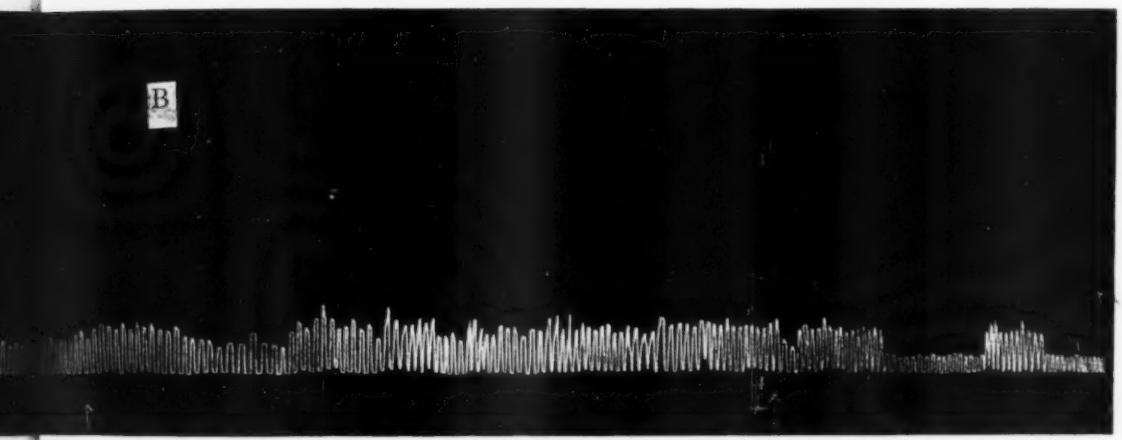


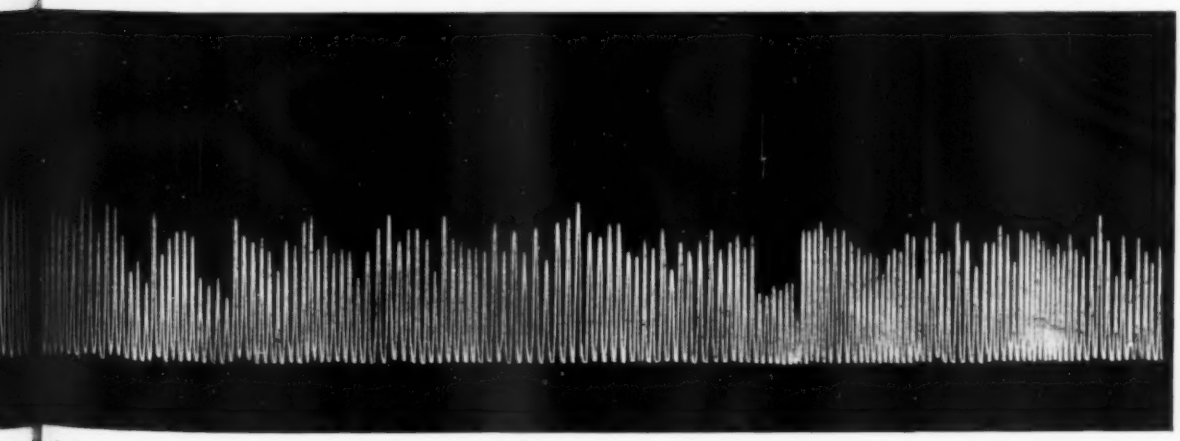
FIG. 7.—A fatigue curve obtained by simply setting the subject ork duri



e it is apparent that he has about reached the limit of his work capacity he is hypnotized while still working. The second half of the tracing (*B*)



, but here in the previous experiment hypnosis is induced, in this experiment suggestions without hypnosis are now given of as we made. The subject works considerably longer than normally, that is, his endurance is increased, but the curve is in



bject work during hypnosis without any suggestions being given at all.

out more emphatically by the fact that the period for recuperation after work in the hypnotic state, that is, the interval necessary for the muscle to make a complete recovery and give a second tracing as extensive as the first, as compared with the recuperative period after work in the waking condition, is startlingly short. Normally, after complete fatigue with a given load a recuperative period of between one and two hours is necessary before a second tracing similar to the first can be obtained. After obtaining a work-curve (Fig. 2) in the hypnotic sleep, however, one can awaken the subject and at once obtain a normal curve of work (Fig. 3) corresponding to the standard work-curve of the waking condition (Fig. 1). One would expect a longer time for recovery after the hypnotic tracing because of the very much greater amount of work done in the hypnotic state. Evidently both subjectively and objectively fatigue in the hypnotic sleep is lessened.

Again and again in the literature the statement is made that suggestions given while the subject is fully awake are as effective as when given during the hypnotic sleep. The records obtained from Experiments IV and V (Figs. 5, *A* and *B;* 6, *A* and *B*) do not seem to bear this out. In Experiment IV the subject after working almost up to the point of fatigue was hypnotized and given suggestions of increased muscular power. The tracing thus obtained (Fig. 5, *A* and *B*) shows several interesting facts: First, that each contraction is at once markedly increased in extent under hypnotic suggestion; secondly, that in extent the contractions tend to equal one another instead of becoming less and less extensive as fatigue comes on, as in the typical waking fatigue curve; and thirdly, that it seems possible to continue to produce such a work-curve indefinitely. In contrast to this the records from Experiment V (Fig. 6, *A* and *B*), in which at the point where in the previous experiment the subject had been hypnotized we now gave without hypnosis suggestions of the same kind as had been given previously during hypnosis, show that in this experiment the contractions do not at once increase in extent nor do they tend to show any improvement as far as extent is concerned; they continue along at about the same level, differing only from the subject's standard fatigue curve in that they are maintained for a longer period of time. In other words, the endurance is increased, but the actual amount of work done is so much greater when the suggestions are given during hypnosis than when given during the waking condition that it would seem reasonable to conclude that suggestions given during the hypnotic sleep are much more effective than the same suggestions given in the absence of hypnosis. Hence, we may say that wherever suggestion is indicated as a therapeutic agent hypnosis should be the method of choice.

As regards the problem which Experiment VI was designed to solve, namely, the effect that hypnosis *per se*, regardless of verbal suggestions, exerts upon muscular work the results were vitiated by the fact that this was the last experiment done in the series and, accordingly, it is probable that by the conditioned-reflex mechanism the subject conducts himself exactly as though verbal suggestions were given at this time just as in the previous similar situations. Nevertheless, we present the record obtained (Fig. 7) for what it is worth. It corresponds in general to all of the other records obtained in the hypnotic sleep where suggestions of increased muscular efficiency were given throughout the experiment.

All the results obtained above were controlled by repeating them on the same subject and duplicating them on all the subjects used, seven in all. It is recognized that there are many phases of even this particular problem still untouched, but the results obtained thus far, though fragmentary, justify this preliminary report.

In conclusion I wish to express my thanks to Professors Meyer, Howell and Watson who were ready at all times to give me the benefit of their advice. Dr. Benjamin Sachs rendered helpful assistance in some of the experiments.

THE GRANULES, VACUOLES AND MITOCHONDRIA IN THE SYMPATHETIC NERVE-FIBERS CULTIVATED *IN VITRO*

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(From the Department of Embryology, Carnegie Institution of Washington, and The Johns Hopkins Medical School)

INTRODUCTION

The living sympathetic nerve-fibers are easily cultivated, in saline and other solutions, from explants of the intestine of chick embryos of 4 to 12 days' incubation (Lewis and Lewis, 1912). The fibers extend outward on the under surface of the coverslip and usually form a complicated and irregular network. The larger nerves have a more or less radial direction and are connected by branches which extend between them at various angles.

The material described by Lewis and Lewis consisted in part of specimens fixed in osmic acid vapor and stained with iron-hæmatoxylin. In these preparations the neurofibrils were found to vary in number in nerves of different sizes and they did not extend into the nerve endings. In places where the fibers were much flattened out the neurofibrils were seen to consist of fine granules. No attempt was made to describe other structures in the fibers. It is now known that it is impossible to distinguish between mitochondrial granules and granules of other origin in material stained with iron-hæmatoxlyin. The later application of the so-called vital stains to tissue cultures has opened up new possibilities for the cytologist, and at the suggestion of Dr. Lewis I examined the structure of the living sympathetic nerve-fibers with and without the aid of vital dyes.

MATERIALS AND METHODS

Cultures were made in the usual manner. Small bits of the intestine of chick embryos from 6 to 9 days incubation were used. Most of the cultures were grown in Locke's solution plus 0.25 per cent dextrose plus 10 per cent chicken bouillon (Locke-Lewis solution). The nerve-fibers usually appeared in from 10 to 24 hours and often grew out for long distances in 24 to 48 hours. Not all of the explants, however, gave rise to nerve-fibers.

The living cultures were studied both with and without the use of the vital dyes. Neutral red (about 1 to 20,000 in Locke's solution) was used for the granules and vacuoles and janus black No. 2 (about 1 to 10,000 in Locke's solution) for mitochondria. It is very much easier to study the granules and mitochondria after they have taken up these dyes than in the unstained specimens. The living fibers were first examined unstained; then the culture was washed with one or more drops of the neutral red, after which a drop or two of the janus black No. 2 was placed on the preparations and the excess fluid sucked off with a fine pipette. Sometimes the neutral red and janus black No. 2 were made up together in the same solution, or the janus black No. 2 was put on the specimen before the neutral red. The neutral red was taken up in a few seconds by the granules and vacuoles, while the janus black No. 2 required several minutes to color the mitochondria.

OBSERVATIONS

The nerve-fibers in explants from 6-day embryos resembled those from the older ones described in more detail farther on. The mitochondrial rods and granules were irregularly arranged, except that they were more often at the periphery of the fibers than in the central part. The rods had their long axes more or less parallel to that of the fiber. Some of them moved a little, usually up or down the fiber. The granules which took up the neutral red, when present, were scattered and few in number. A few colorless vacuoles which did not take up neutral red were also found along the fibers and in the nerve endings.

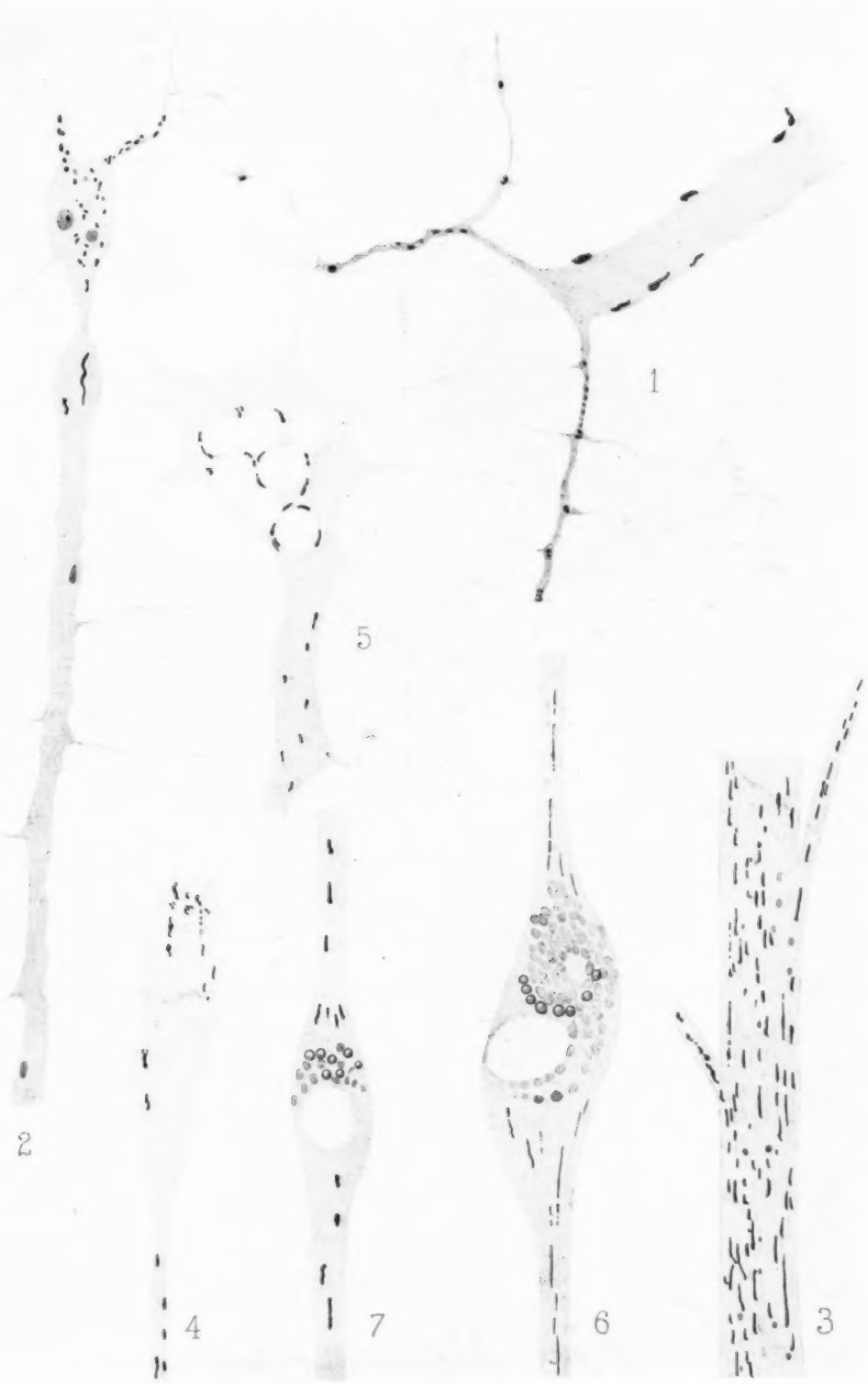
A typical fiber in a 48-hour culture from a 7-day chick embryo, shown in Fig. 1, contained a few scattered, rod-shaped mitochondria along the periphery of the nerve stem. In the branching nerve endings they were granular in form and situated, for the most part, in the small nodes from which delicate lateral branches were given off. In this particular fiber most of these small nodes had one mitochondrium, a few showed two or three. Mitochondria were also scattered in places on the branches between the nodes. There were no neutral red granules or vacuoles in this part of the nerve and no indications of neurofibrils were to be seen.

In another 48-hour culture of a 7-day chick embryo (Fig. 2), a somewhat different condition existed. There were very few mitochondria along the fiber and these had no definite relation to the periphery. The slightly expanded ending contained numerous mitochondria in the form of granules and short rods and such mitochondria were present also in the two principal branches. There were no indications of neurofibrils. In another similar culture the larger nerve trunks, as a rule, possessed many rod-like mitochondria arranged with their long axes more or less parallel to the long axis of the fiber (Fig. 3). The smaller branches and nerve endings in this same culture contained fewer mitochondria than did the larger trunks (Fig. 4). Only a few scattered granules had taken up the neutral red. No indications of neurofibrils were observed. In some fibers which lived 4 days there was no noticeable increase in the number of granules or vacuoles which take up the neutral red, such as usually occurs in the mesenchyme cells. This may be due to the fact that in the case of the nerve-fiber we are dealing with a process of the cell and not with the cell body. In addition to the neutral red vacuoles, which were not numerous, some of the fibers and endings contained clear, unstained vacuoles. These were evidently different from the vacuoles which take up the neutral red, since they were often side by side, yet one type took up the red while the other did not.

The cultures from 8-day embryos were similar to those from the 7-day ones. The nerves contained mitochondrial rods and granules which varied in number in different fibers and in different nerve endings. In some they were numerous, while others contained only a few. As in the cultures from 7-day chicks, the rod-shaped mitochondria had their long axes parallel to the long axis of the fiber and did not form definite chains or rows. The mitochondria were more numerous in the larger nerve stems than in the smaller ones. The number of granules which took up neutral red varied greatly in different fibers and in different nerve endings. In the 24-hour cultures they varied as much and did not seem to be any less numerous than in the 3-day cultures. Some of the nerve endings in 3-day cultures were devoid of any of the granules or vacuoles which take up the neutral red, or contained, at most, only one or two (Fig. 5). Sometimes, even in the 24-hour cultures, there were more neutral red granules than mitochondria. Many of the fibers and endings, as in the cultures from the 7-day embryos, contained large unstained vacuoles (Fig. 5). These seem to be more common in cultures from older embryos than in those from younger ones and were found in the 24-hour growths as well as in the older ones.

In addition to the distribution of mitochondria and granules in the fibers and nerve endings, there was usually to be found a marked accumulation of granules and vacuoles in the larger nodes of the nerves, as shown in Figs. 6 and 7. These nodes consist of a mass of granules and small vacuoles which take up the neutral red. This mass is on the peripheral side of a clear area; on the proximal side of this area there may be a few granules. The large mass of neutral red granules and vacuoles has sometimes a more or less clear area at its center. The nodes have the appearance of a degenerating cell with a mass of granules and vacuoles about a centrosphere which lies at one side or at one end of a clear area—the nucleus.

In cultures from 9-day chick embryos there was as much variation in the number and arrangement of the mitochondria and granules as in those from younger embryos. One cannot distinguish the living nerve-fibers in the cultures of 9-day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embryos from those cultivated from a 7-, 8-, or even a 5- or 6-day embryo.

THE MITOCHONDRIA

In none of the fibers and nerve endings examined was there ny suggestion of a regular distribution of the mitochondria, uch as one would expect to find if they are to give or are iving rise to neurofibrils. Moreover, no neurofibrils were seen n the living fibers.

Neurofibrils were described by Lewis and Lewis (1912) in xed cultures of the same ages and length of growth as the nes examined in this study. The fact that neurofibrils were ot seen in the living fibers is no proof that they were not here; on the other hand, the fact that they can be seen in imilar fibers, when fixed and stained, is no proof that they xist in the living, for they may very well be coagulation roducts.

Although the distribution of mitochondria varied both in umber and position there was more or less regularity in their rientation, especially in the fibers where the rods and short hreads usually had their long axes parallel with the long axis the fiber. One might argue that this peculiar orientation as caused by the presence of invisible neurofibrils. On the ther hand, it might equally well be due to some sort of a olecular or metabolic arrangement of the cytoplasm. The itochondria show a moderate degree of movement. We have o method of determining whether this is passive, due to ytoplasmic changes, or active, on the part of the mitochondria. he movements are slower and differ in character from those f the granules which take up the neutral red. The mitohondria seem to be more numerous in the larger nerve-fibers nd in the regions nearer the explant.

THE GRANULES

The granules which take up the neutral red varied greatly size and number, being irregularly distributed along fibers nd in the nerve endings. The larger nodes, however, especially in the distal half, were crowded full of them. The ranules usually exhibited considerable movement, especially in a longitudinal direction along the fiber and at the periphery. They moved more rapidly than the mitochondria and over longer distances, sometimes in a jerky manner.

The granules did not seem to have any definite orientation nor were they increased in number in the older cultures. Their significance is unknown, but it is not unlikely that they are degeneration granules, such as those described by Lewis (1919) in fibroblasts. Vacuoles which take up neutral red were rarely observed except in the larger nodes.

DESCRIPTION OF PLATE[1]

FIG. 1.—Sympathetic nerve and branched ending with mitochondia. 48-hour culture from intestine of 7-day chick embryo.

FIG. 2.—Sympathetic nerve and ending with mitochondria and a few granules and vacuoles which take up neutral red. 48-hour culture from intestine of 7-day chick embryo.

FIG. 3.—Large sympathetic nerve with many mitochondria and granules. 48-hour culture from intestine of 7-day chick embryo.

FIG. 4.—Nerve ending from nerve shown in Fig. 3, with mitochondria and granules.

FIG. 5.—Nerve ending with mitochondria and large vacuoles which do not take up neutral red. 3-day culture from intestine of 8-day chick embryo.

FIG. 6.—Node on sympathetic nerve with a large mass of granules and vacuoles, which take up neutral red, a few fat globules and a clear area. 5-day culture from intestine of an 8-day chick embryo.

FIG. 7.—Somewhat similar node. 3-day culture from intestine of 8-day chick embryo.

[1] The figures are all free-hand drawings from living cultures to which neutral red and janus black No. 2 were added after the culture had grown out. The blue-black mitochondria of the living are represented in black and the granules and vacuoles, which take up the neutral red, in grey.

BIOGRAPHY OF SIR WILLIAM OSLER

Lady Osler has requested me to prepare a biography of her husband, and I will be most grateful to anyone who chances to see this note, for any letters or personal reminiscences, or for information concerning others who may possibly supply letters.

Copies of all letters, no matter how brief, are requested, and if dates are omitted it is hoped that they may be supplied if possible.

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